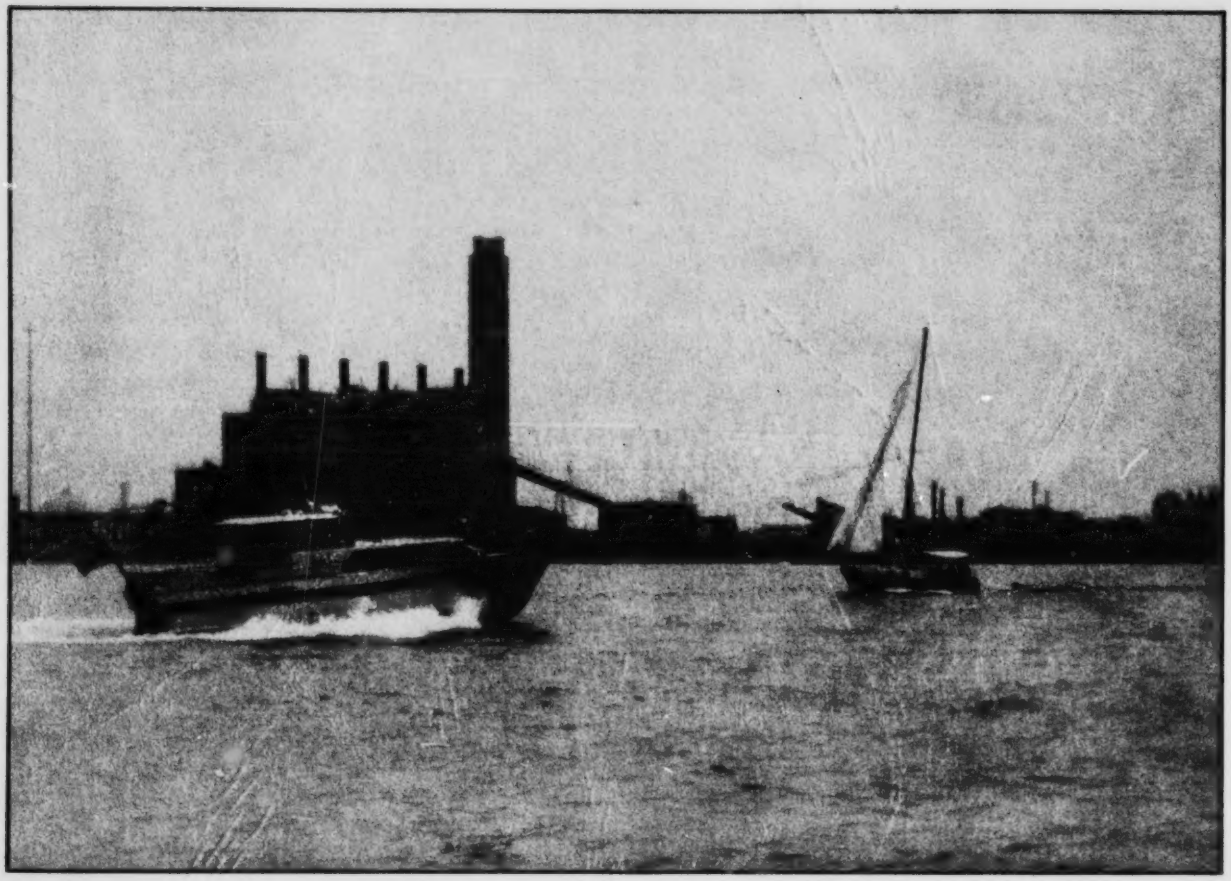
ST. CLAIR RIVER ORGANICS STUDY

BIOLOGICAL SURVEYS

1968 AND 1977



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ST. CLAIR RIVER ORGANICS STUDY

BIOLOGICAL SURVEYS

1968 and 1977

Water Resources Assessment Unit
Technical Support Section
Southwestern Region

Ministry of the Environment 1979

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FOREWORD

Investigation of organic chemicals in industrial effluents along the St. Clair River commenced in 1975 after the adoption of gas chromatography - mass spectrometry analytical methodologies by the Laboratory Services Branch of the Ministry of the Environment made the detection of low concentrations of such compounds possible. In a preliminary report, 'Organic Compounds of Industrial Origin in the St. Clair River', developed as an internal working document in January of 1977, positive identification was made of some 47 organic compounds discharged to the St. Clair River.

The St. Clair River Organics Study Group was formed early in 1977 in response to concerns about the presence and significance of the organic compounds identified, particularly in relation to possible effects on public water supplies downstream and the potential bio-accumulation of such compounds by fish resident in or frequenting this important waterway. Also, it was felt that a comprehensive assessment of water quality conditions and aquatic life was warranted to permit a comparision with unpublished biological data collected in 1968.

Representation on the Study Group included staff from various branches of the Ministry of the Environment and the Special Studies and Services Branch of the Ministry of Labour. Early in its deliberations, the Study Group identified the following goal:

> *To assess the presence and significance of organic chemical compounds in the St. Clair River system and to establish from this programme recommendations for control measures and further studies that may be required in relation to human health and environmental effects.*

In order to accomplish the above goal, the following ten objectives were identified:

1. Identification and quantitation of organic compounds in industrial discharges, St. Clair River water, potable water supplies, bottom sediments and fish.

2. Completion of a literature search on the characteristics and effects of the organic compounds identified. Lethal, sub-lethal and synergistic effects of these compounds on human and aquatic life to be considered.

3. Determination of the significance of chlorinating trace amounts of these organic materials in industrial cooling water discharges, sewage plant effluents and in potable water supplies.

4. Determination of the types and concentrations of compounds causing fish toxicity and fish tainting problems.

5. Estimation of the dissolved organics concentration at any point in the river based on effluent quality and flow measurements.

6. Completion of benthic macroinvertebrate, aquatic plant, sediment and water quality studies on the river in terms of biological and common chemical indicators. Results to be compared to survey work carried out in 1968-69. Assessments of mercury levels in sediments to be completed.

7. Determination of the potential carcinogenicity of organic compounds through quick-screening microbiological tests for mutagenesis.

8. Establishment of whether biodegradation or alteration of organic compounds occurs through bacterial action in sediments.

9. Development of recommendations clarifying levels to which contaminants must be reduced, as a basis for necessary treatment and effluent controls.

10. Clarification of the need for additional research to establish potential dangers to human health or the natural environment where this information is lacking.

Work on the component studies related to these objectives progressed throughout 1977 and 1978 and into 1979. As a result of these efforts the following reports will be published during 1979, to form an integrated series covering the objectives defined previously.

(1) Identification and Quantitation of Organic Compounds.
(2) Fish Toxicity and Tainting Evaluations for Selected Industrial Effluents.
(3) Waste Dispersion.
(4) Biological Surveys 1968 and 1977.
(5) The Detection of Mutagenic Activity; Screening of Twenty-three Compounds of Industrial Origin.
(6) Biodegradation of Organic Compounds.

Wherever possible, each of these reports will present conclusions and advance recommendations to achieve an improvement of water quality in the St. Clair River system or to clarify additional research requirements in regard to potential human health or environmental effects.

It is anticipated that subsequent reports dealing with fish toxicity and tainting and the potential carcinogenicity of industrial organic compounds in relation to the St. Clair River will be issued by the Ministry, since these particular components will be the subject of further study by the Limnology and Toxicity Section of the Water Resources Branch and the Microbiology Section of the Laboratory Services Branch, respectively.

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SUMMARY

A marked improvement in water quality as reflected by bottom fauna production has occurred between 1968 and 1977 in the St. Clair River.

A resurgence of bottom-dwelling life forms was evident in the nearshore waters along the Canadian shoreline as evinced by increased numbers and a greater variety of taxa, along with a reduction of the degradation zone of the river. A considerably reduced zone of severe impairment was still evident in 1977 along the Canadian shoreline where benthic organisms generally accepted as sensitive to pollution were absent and those most tolerant to pollution were predominant. Wastes discharged from Canadian sources were found to impact only on nearshore Canadian waters and biota since the strong currents of the shipping channel do not allow for detectable transboundary movement.

It is considered that the recovery of bottom fauna has been a direct result of reductions in the volume and improvements in the quality of industrial and municipal discharges to the river along the Canadian shoreline.

Field observations and the results of sediment analyses revealed that the St. Clair River sediments were contaminated with organic compounds such as PCBs, oil and heavy metals and supported excessive growths of bacterial slimes and aquatic plants.

Elevated concentrations of PCBs in river sediments were documented during 1976, 1977 and 1978. Owing to the lack of historical information it is not possible to establish whether these values were previously of greater magnitude,

assuming that the declining trend noted for mercury as a result of translocation processes would also apply to PCBs. The presence of high concentrations of PCBs in the sediments is of particular concern because of the detection of PCBs in the flesh of several species of fish from the St. Clair River, Lake St. Clair and Lake Huron at concentrations which exceed the guideline established for this contaminant to protect human health.

Aesthetically the surface waters of the St. Clair River have improved substantially since the initial investigations in 1968. Although spills and discharges of petroleum compounds were observed to remain a common occurrence, a qualitative comparison showed the St. Clair River to be visually much cleaner than in 1968. A number of the spills observed in 1977 originated from commercial shipping traffic.

RECOMMENDATIONS

1. The improvements in water quality reflected by improved bottom fauna in the St. Clair River should serve as a stimulus to industries in the Sarnia area to sustain this improving trend by achieving further reductions in oxygen-consuming organic substances, nutrients and other comtaminants.

2. Excessive growths of aquatic plants and bacterial slimes along the Canadian shoreline indicate the need for further reductions in nutrient inputs and low molecular weight organic compounds that are known to stimulate filamentous bacteria. Improved controls of nutrients (carbon, phosphorus and nitrogen) and organic compounds at Imperial Oil Limited, Esso Chemical Canada Limited, Polysar Limited, Dow Chemical of Canada Limited, Sunoco Incorporated and Shell Canada Limited, in particular, would enhance the biological productivity and recreational and aesthetic quality of the waterway.

3. Increased emphasis should be placed on the elimination of spills of oils, tars and other petroleum-type compounds, including improved surveillance and controls of discharges from commercial shipping vessels along the St.Clair River system.

4. Efforts should be made to clearly establish that PCBs present in sediments in the St. Clair River system are not the result of continuing contamination, either from present processes or as leachate possibly associated with spills onshore or as inputs from waste disposal areas.

5. Reductions in discharges of phenolic compounds should be strived for by Polysar Limited, Dow Chemical of Canada Limited and Shell Canada Limited to minimize tainting effects of fish resident in or frequenting the St. Clair River.

6. Although many areas of the Canadian shoreline of the St. Clair River were contaminated with various heavy metals, a pocket of sediments in the vicinity of Mueller Limited had markedly increased concentrations of copper, lead, zinc and iron. More detailed sampling is required to establish the source and significance of these contaminated sediments.

ACKNOWLEDGEMENTS

Mr. S. Thornley[a] was responsible for supervision of the 1977 survey and overall report preparation. The initial survey in 1968-69 was planned and supervised by D. S. Osmond[b]. Mr. J. D. Westwood[c] was responsible for data collection in 1969 and was in charge of field operations for all aspects of the 1977 survey. Statistical methods were developed by R. Griffiths[d]. Appreciation is extended to staff of the Industrial Abatement Section at the Sarnia District Office and others in the Southwestern Region of the Ministry of the Environment who contributed to report preparation and critical review.

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c. Biologist's Assistant, Ontario Ministry of the Environment, London, Ontario.

d. Mr. Griffiths' methodology was developed in conjunction with the Zoology Department of the University of Western Ontario as partial requirement for his Honours Bachelor of Science Degree. Mr. Griffiths is presently pursuing a post-graduate degree at the Institute of Animal Resource Ecology, Vancouver Campus, University of British Columbia.

INTRODUCTION

In 1918, the International Joint Commission (IJC) provided results of studies of the water quality of the St. Clair River as part of an overall water pollution report on boundary waters. This report dealt principally with bacterial contamination. In a second more comprehensive report in 1951, the IJC rated the upper St. Clair River among the four most heavily polluted areas in the Lake Huron-Lake Erie section of Great Lakes boundary waters. Oils, greases, bacteria and phenolic wastes were considered of greatest significance at that time.

Annual water quality studies of the St. Clair River by the Ontario Water Resources Commission (OWRC) began in 1966 when the province became actively involved in the IJC's Lower Great Lakes Reference Study. Annual summaries indicated improvement over the 1946-48 IJC survey (1951 report) although concentrations of coliform bacteria and phenols still exceeded IJC limits.

Biological surveys undertaken by T. W. Beak since 1957 for the St. Clair Research Committee (now the Lambton Industrial Society) repeatedly indicated varying degrees of impairment of benthic communities in Canadian waters from Sarnia to Port Lambton.

During the summer of 1968, as part of the IJC's Lower Great Lakes Reference, the Biology Branch of the OWRC conducted a biological survey of the river from Lake Huron to Port Lambton that emphasized sampling along the Canadian shoreline. Inspired in part by preliminary findings of the 1968 study, complementary investigations of water and

sediment quality were undertaken in 1969. These studies were undertaken (1) to assess the impact of industrial and municipal waste discharges on the aquatic environment and specifically upon bottom-dwelling fish-food organisms and (2) to document possible effects of these waste discharges on the major uses of water on the Canadian side of the river.

The most recent IJC report dealing with the St. Clair River was released in 1974 and identified elevated concentrations of bacteria and phenols at localized areas along the Canadian shoreline. The report also noted that phosphorus and chloride concentrations had generally decreased since 1968. It identified oils and dissolved organics from Canadian waste sources as having affected the palatability of fish and also contained information based on unpublished data from the OWRC's biological investigations in 1968 which identified disruptions in the benthic macroinvertebrate communities along the Canadian shoreline.

A second major biological assessment of the St. Clair River was conducted during the summer of 1977 by the Ontario Ministry of the Environment. Two sets of biological data were collected, one during the May-June period and one during the July-August period. The 1977 assessment was developed as an integral part of the broader St. Clair River Organics Study established to investigate the presence and significance of organic compounds in the water, sediments and biota of the St. Clair River. The biological survey was designed to afford a comparison with the results of the 1968-69 study.

This report summarizes the results of biological investigations of the St. Clair River conducted during 1968-69 and 1977 and interprets the water quality conditions existent at these widely separated intervals.

DESCRIPTION OF STUDY AREA

ST. CLAIR RIVER VALLEY

Flowing some 64 kilometres in a southerly direction, the St. Clair River joins Lake Huron in the north with Lake St. Clair in the south (Figure 1). The difference in elevation between the two lakes is only about 1.5 metres. The river is incised into the Lambton Clay Plain which consists of glacial till covered by a thin veneer of lacustrine clay.

From Sarnia to Port Lambton, the river averages about 0.8 kilometres in width and ranges in depth from 8 to 18 metres. Stag Island, 14 kilometres downstream from Lake Huron and Woodtick (Fawn) Island, 35 kilometres downstream (both in Canadian waters) are the only islands in this stretch of the river. Evidence of the St. Clair Flats, the delta occupying the lower third of the river, is seen first at Port Lambton where the Chenal Ecarte ("the Snye") branches off the main channel and winds its way into Lake St. Clair at Mitchell's Bay. The South Channel which is the major navigational route, the Chenal Ecarte and the Middle Channel carry about 68 percent of the total flow to the main body of Lake St. Clair, the remainder exiting from several other channels.

Records of streamflow are available from 1860 to the present. From 1965 to 1977, the average annual flow was 5520 cubic metres per second. The highest annual average flow over this period of record was 6150 cubic metres per second occurring in 1973 and 1974. The lowest annual average flow over this period of record was 4620 cubic metres per second, which occurred in 1965. The annual average flows

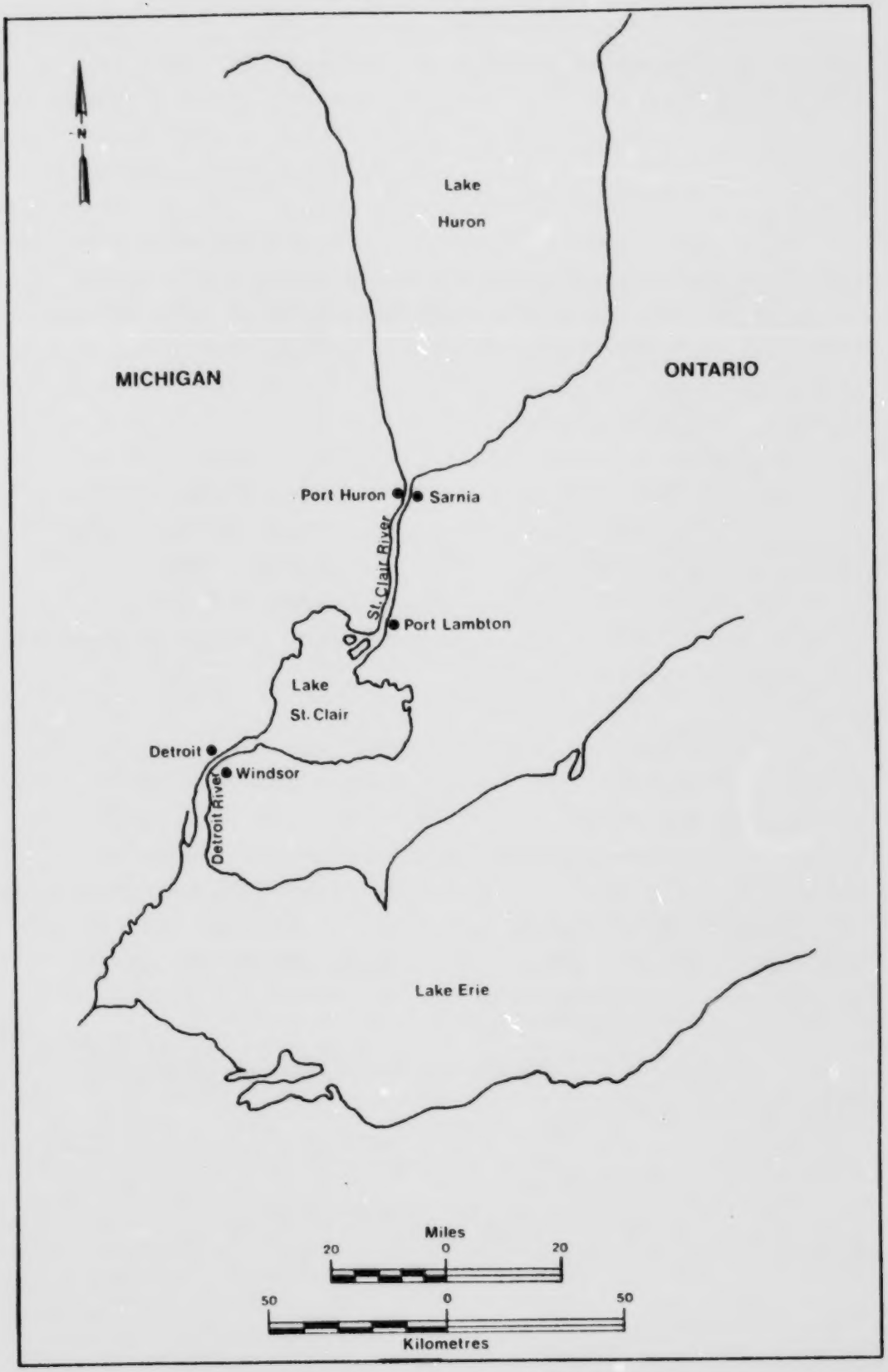


Figure 1. Location map of the St. Clair River.

during the two major surveys in 1968 and 1977 were very similar at 5240 and 5180 cubic metres per second, respectively (Figure 2).

Six cities - five in the United States and one in Canada - are located along the river (Figure 3). Sarnia (1978 population 52,854) is the most heavily industrialized centre on the St. Clair River, its strong industrial base attributable to large petroleum refineries and petrochemical plants. Major industries within the Sarnia city limits in 1968 included Imperial Oil Limited, Esso Chemical Canada Limited, Polysar Limited, Dow Chemical of Canada Limited, and Sunoco Incorporated (Plate 1). No new major industries have located within the City of Sarnia since 1968; however, Petrosar Limited and Union Carbide Canada Limited have located near Corunna and commenced discharging wastes to the St. Clair River during 1977.

Communities situated downstream from Sarnia are Corunna, Mooretown, Courtright, Sombra and Port Lambton. Shell Canada Limited, Ethyl Corporation of Canada Limited, Dupont Canada Incorporated, Allied Chemical Canada Ltd., Ontario Hydro's Lambton Generating Station, Beker Industries of Canada Limited, Canadian Industries Limited and Chinook Chemicals Limited, are situated along the river between Sarnia and Port Lambton (Figure 3).

Numerous cottages are also located along the St. Clair River (Plate 2).

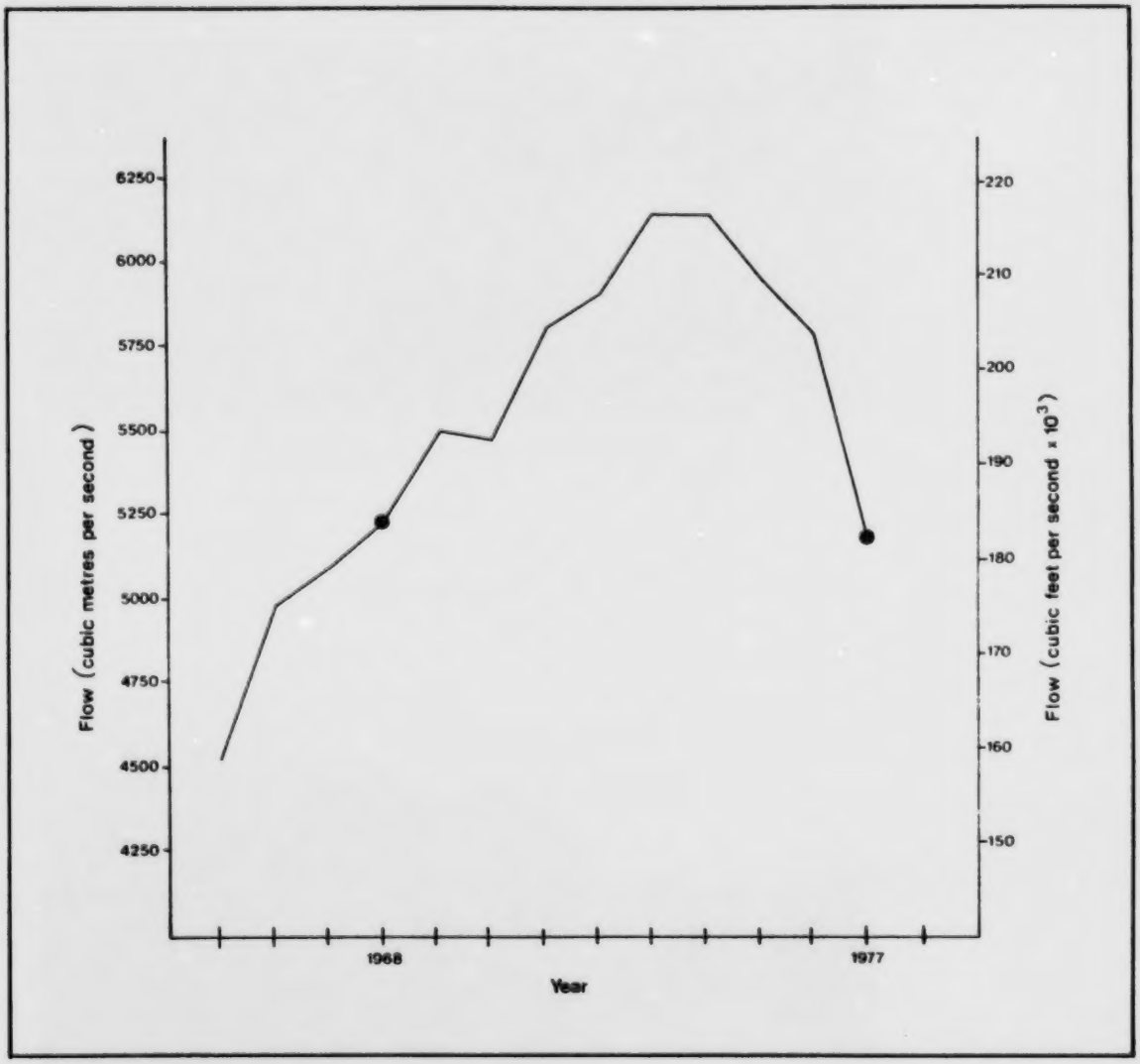


Figure 2. Average annual flows for the St. Clair River for 1965 to 1977.

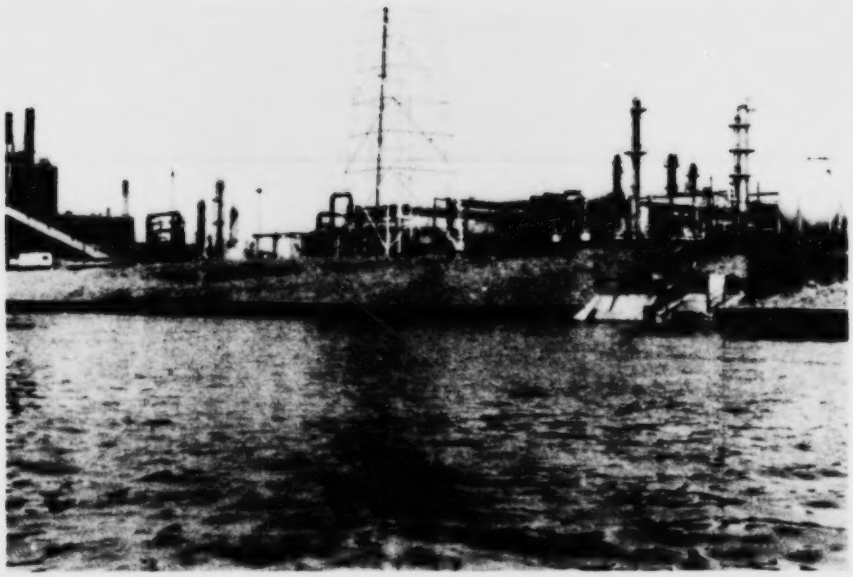
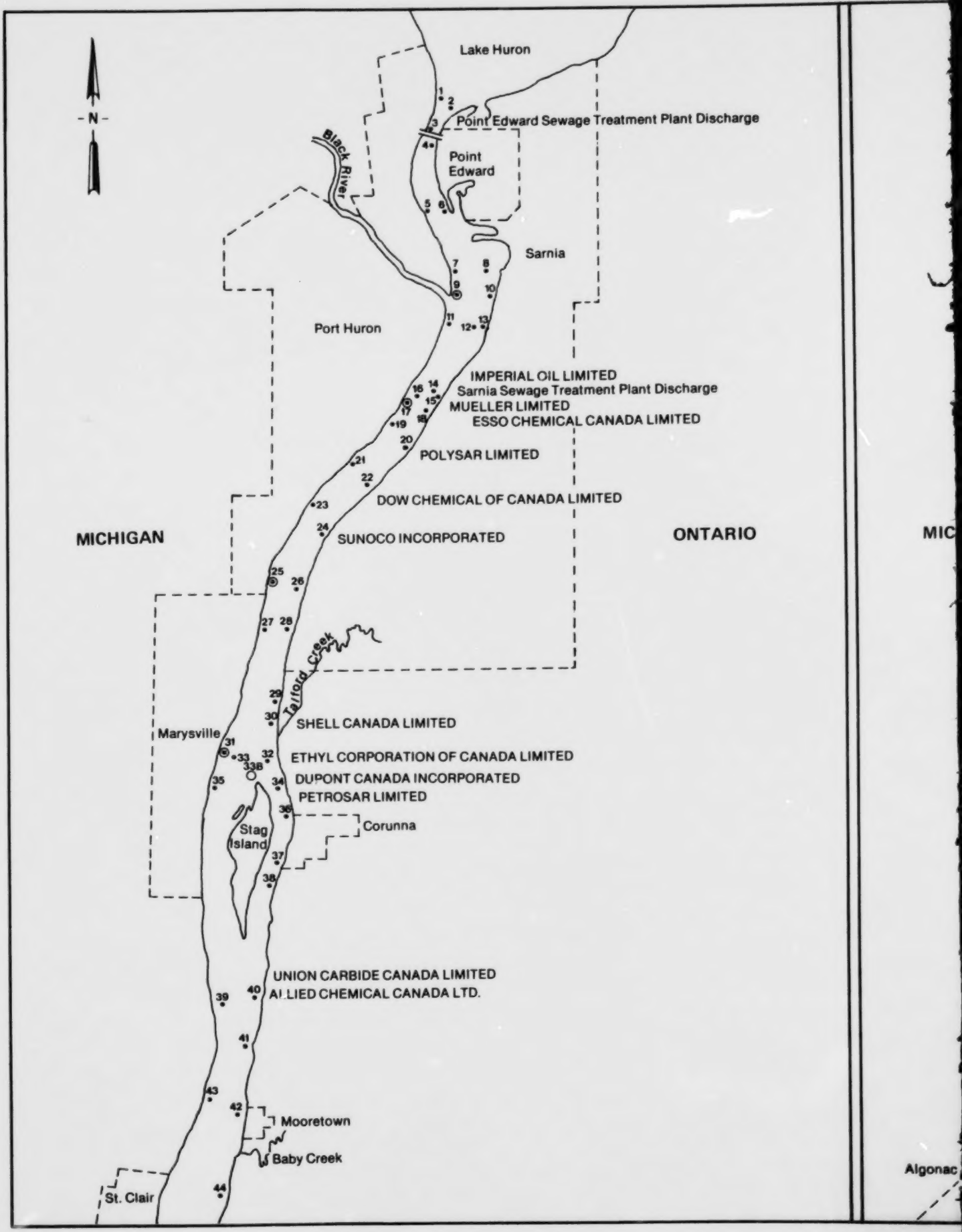


Plate 1. Industry along the Canadian side of the St. Clair River.

Plate 2. Cottages on Stag Island.


N
Lake Huron
Point Edward Sewage Treatment Plant Discharge
Point Edward
Black River
Sarnia
Port Huron
IMPERIAL OIL LIMITED
Sarnia Sewage Treatment Plant Discharge
MUELLER LIMITED
ESSO CHEMICAL CANADA LIMITED
POLYSAR LIMITED
DOW CHEMICAL OF CANADA LIMITED
SUNOCO INCORPORATED
MICHIGAN
ONTARIO
Telfold Creek
SHELL CANADA LIMITED
Marysville
ETHYL CORPORATION OF CANADA LIMITED
DUPONT CANADA INCORPORATED
PETROSAR LIMITED
Corunna
Stag Island
UNION CARBIDE CANADA LIMITED
ALLIED CHEMICAL CANADA LTD.
Mooretown
Baby Creek
St. Clair
Algonac

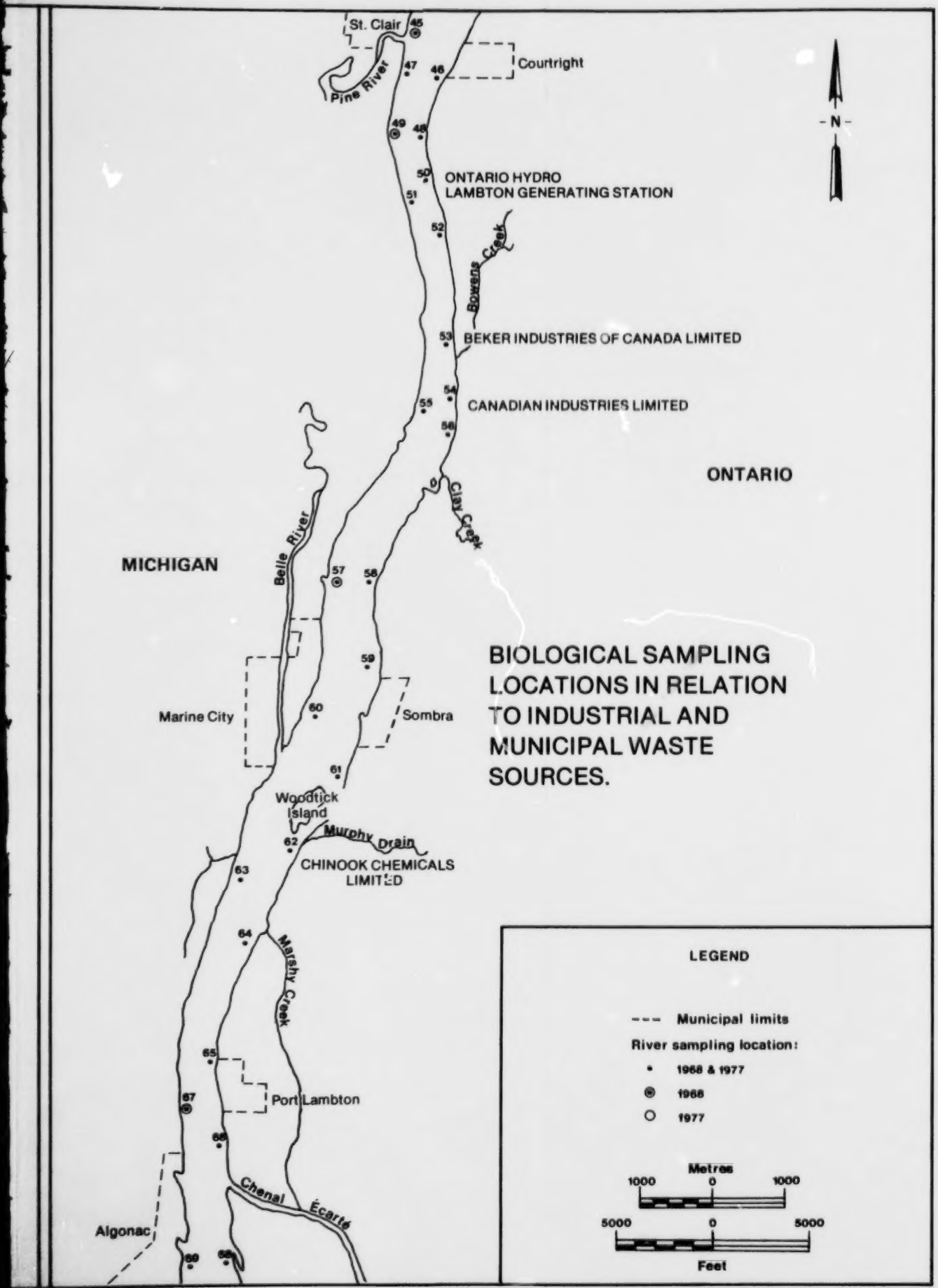

St. Clair
45
Courtright
Pine River
47
46
49
48
50
ONTARIO HYDRO
LAMBTON GENERATING STATION
51
52
Bowens Creek
53
BEKER INDUSTRIES OF CANADA LIMITED
54
55
CANADIAN INDUSTRIES LIMITED
56
ONTARIO
Clay Creek
MICHIGAN
Belle River
57
58
59
Marine City
60
Sombra
61
Woodtick
Island
Murphy Drain
62
CHINOOK CHEMICALS
LIMITED
63
64
Marshy Creek
65
Port Lambton
67
66
Chenal Écarté
Algonac
69
68
N
BIOLOGICAL SAMPLING
LOCATIONS IN RELATION
TO INDUSTRIAL AND
MUNICIPAL WASTE
SOURCES.
LEGEND
Municipal limits
River sampling location:
1968 & 1977
1968
1977
Metres
1000
0
1000
5000
0
5000
Feet

Figure 3

MUNICIPAL AND INDUSTRIAL WASTE LOADINGS

At the time of the 1968-69 investigations, domestic wastes from Point Edward and Sarnia received only primary treatment based on design capacities of 2590 and 36,360 cubic metres per day, respectively. Secondary treatment was provided at the Corunna STP. Domestic wastes in the remaining Canadian municipalities along the river were treated by household septic tanks and tile beds. Wastes entering the St. Clair River from the five U.S. municipalities received primary treatment and wastes from one centre were untreated.

A summary of municipal waste treatment facilities operative at the time of the 1977 survey is presented in Table 1. Four communities (Corunna, Courtright, Sombra and Port Lambton) have upgraded domestic waste treatment since 1968-69 and now have central sewage treatment works (secondary plants or lagoons).

Many major industries producing a wide range of petroleum and petrochemical products are situated along the Canadian shoreline of the St. Clair River. Information on waste discharges from the larger industries is summarized in Tables 2 and 3.

WATER USE

The St. Clair River is both a source of water supply and a receiver of wastes from municipalities and industries located along its course. As a connecting channel in the Great Lakes the river receives heavy commercial shipping traffic and is popular with pleasure craft operators.

Table 1. Summary of municipal waste treatment facilities along the Canadian side of the St. Clair River.

Municipality	Treatment capacity (cubic metres/day)	Type of treatment	Annual loadings to the St. Clair River (kilograms)		
			BOD_5	Suspended solids	Total phosphorus
Point Edward [a]	2,590	Primary	40,800	31,300	1,700
Sarnia [a]	65,900	Primary	550,000	355,700	10,353
Corunna [a]	1,450	Extended aeration	4,300	3,900	480
Courtright [a]	570	Extended aeration	210	530	110
Sombra [b]	400 (26 acres)	Lagoons	247	1,317	26
Port Lambton [b]	560 (36 acres)	Lagoons	730	3,636	59

a 1977 data

b 1978 data

All treatment facilities employ phosphorus removal

Table 2. Total plant effluent loadings for major Canadian industries [a].

Industry	Total gross loadings (kg/day except phenols in gm/day)						
	Total nitrogen	Total solids	Suspended solids	Chloride	Phenols	TOC	Total carbon
Imperial Oil Limited	430	40,300	2,420	5,300	2,900	1,800	5,630
Esso Chemical Canada Limited	43	3,590	35	900	1,090	480	622
Polysar Limited	590	179,000	8,000	42,700	55,100	12,400	25,100
Dow Chemical of Canada Limited	1,500	626,000	16,900	277,000	9,780	6,950	23,000
Sunoco Incorporated	120	28,700	750	11,100	670	430	1,650
Shell Canada - contaminated	200	18,900	840	7,300	3,080	540	2,590
Limited - clean	52	23,600	920	4,300	930	470	2,770
Ethyl Corporation of Canada Limited	17	49,200	420	24,200	310	230	900
Dupont Canada Incorporated	9	4,410	150	500	100	170	674
Petrosar Limited	95	1,290	350	3,180	43	180	605
Allied Chemical Canada Ltd.	9	3,110	95	550	100	70	346
Beker Industries - cooling water	310	12,800	1,300	860	100	320	1,920
of Canada Limited - API	43	600	26	230	3	10	35
Canadian Industries Limited	530	50,900	1,380	3,200	380	930	6,700
Total	3,948	1,042,400	33,586	381,320	74,586	24,980	72,542

a Results are from a three month period during the summer of 1977 and are average values from six separate sampling dates each of which was a composite consisting of twenty-four hourly grabs.

Table 3. Major Canadian industries, their waste characteristics and major products.

Industry	Waste characteristics	Major products
Imperial Oil Limited	refinery waste water	refined petroleum products
Esso Chemical Canada Limited	benzene, toluene, xylene, vinyl chloride monomers, phenol, hexachlorinated compounds, naphthalene	petrochemicals
Polysar Limited	phenol, hexachlorinated compounds, aliphatics, benzene, isoprene, styrene, chlorinated aromatics and aliphatics	synthetic rubbers
Dow Chemical of Canada Limited	aromatics, chlorinated organics, styrene, ethylbenzene, chlorides	solvents, glycols, polymers, chlorine, caustics
Sunoco Incorporated	refinery waste water	gasoline, kerosene, bunker oil, fuel oil
Shell Canada Limited	refinery waste water	gasoline, diesel fuel furnace oil, bunker fuel, aromatic solvents, (benzene, toluene)
Ethyl Corporation of Canada Limited	organic lead,chlorinated compounds	tetra-ethyl lead, tetra-methyl lead, pharmaceuticals
Dupont Canada Incorporated	cooling water	pelletized polyethylene
Petrosar Limited	refinery waste water	ethylene, petrochemical refining, fuel oils
Union Carbide Canada Limited	cooling water	polyethylene
Allied Chemical Canada Ltd.	toluene di-isocyanate	toluene di-isocyanate
Beker Industries of Canada Limited	ammonia	ammonia
Lambton Generating Station	cooling water	electricity
Canadian Industries Limited	ammonia	ammonia
Chinook Chemicals Limited	all wastes recycled	methylamines

The St. Clair River is used heavily by a large number and variety of waterfowl and fish. The entire river has been identified by the Canadian Environmental Protection Service as a sensitive area for waterfowl during all seasons. Several riverside parks are operated by the St. Clair Parkway Commission which offer a variety of facilities including scenic picnic and swimming areas, campgrounds and a golf course. The river is used by local residents for domestic water supply, boating, swimming, fishing, hunting, waterskiing and skating.

At the time of the 1968-69 surveys, the City of Sarnia obtained water from the head of the river for its own use and for Point Edward, Corunna and portions of the townships of Moore and Sarnia. Average daily consumption in 1969 was approximately 49,000 cubic metres.

Sombra obtained water from an intake projecting approximately 190 metres into the river and Port Lambton also took its water from the St. Clair River.

In 1975, the Ministry of the Environment completed the Lambton Area Water Supply System. This system distributes an average of 181,840 cubic metres of water per day to Sarnia and downstream municipalities and to inland villages where potable water is in short supply. Other domestic water takings along the Canadian shoreline in 1977 were: the Stag Island Water Supply System (operative approximately between May and October); Canadian Industries Limited, Sombra Township; Chinook Chemicals Limited, Water Works, Sombra Township; Woodtick (Fawn) Island Water Works and Walpole Island Indian Reserve Water Works.

The rate of industrial consumption of water from the St. Clair River totalled approximately 4.5×10^6 cubic metres per day during 1968, an annual average daily flow approximately equal to that of the Grand River at Brantford, Ontario. The consumption of water for industrial use in 1977 was considerably reduced to approximately 2.3×10^6 cubic metres per day.

During 1968, only three years into its schedule of parkland development, the St. Clair Parkway Commission had greatly improved the appearance of the river shoreline. Ten parks ranging from small picnic areas to an overnight campground with 58 campsites received heavy use during summer months. In 1969, when Cathcart Park had 48 campsites, 7000 campers used the park.

The St. Clair Parkway now contains 14 parks and a Championship Golf Course providing a wide range of recreational opportunities (Figure 4). Over 16,000 campers used Cathcart Park during 1977. Of the more than 46,000 campers who used Marine Park, Cathcart Park and Lambton-Cundick Park, approximately 38 percent stayed for three days or longer. Some of the water-related recreational opportunities provided along the St. Clair Parkway include sailing regattas, boating, fishing, bathing and seaway observation. Nearly 5,000 boaters launched their boats at Marine Park during 1977.

The St. Clair River supports a varied and important fishery. Although there is no commercial fishery in the St. Clair River itself, the river is a major migratory route for species which contribute to the commercial fisheries of Lakes Huron, Erie and St. Clair. At least 17 fish species were represented by either egg and/or larval life stages in an approximately 2.7 kilometre reach near the Belle River Power Plant (Texas Instruments Incorporated, 1975).

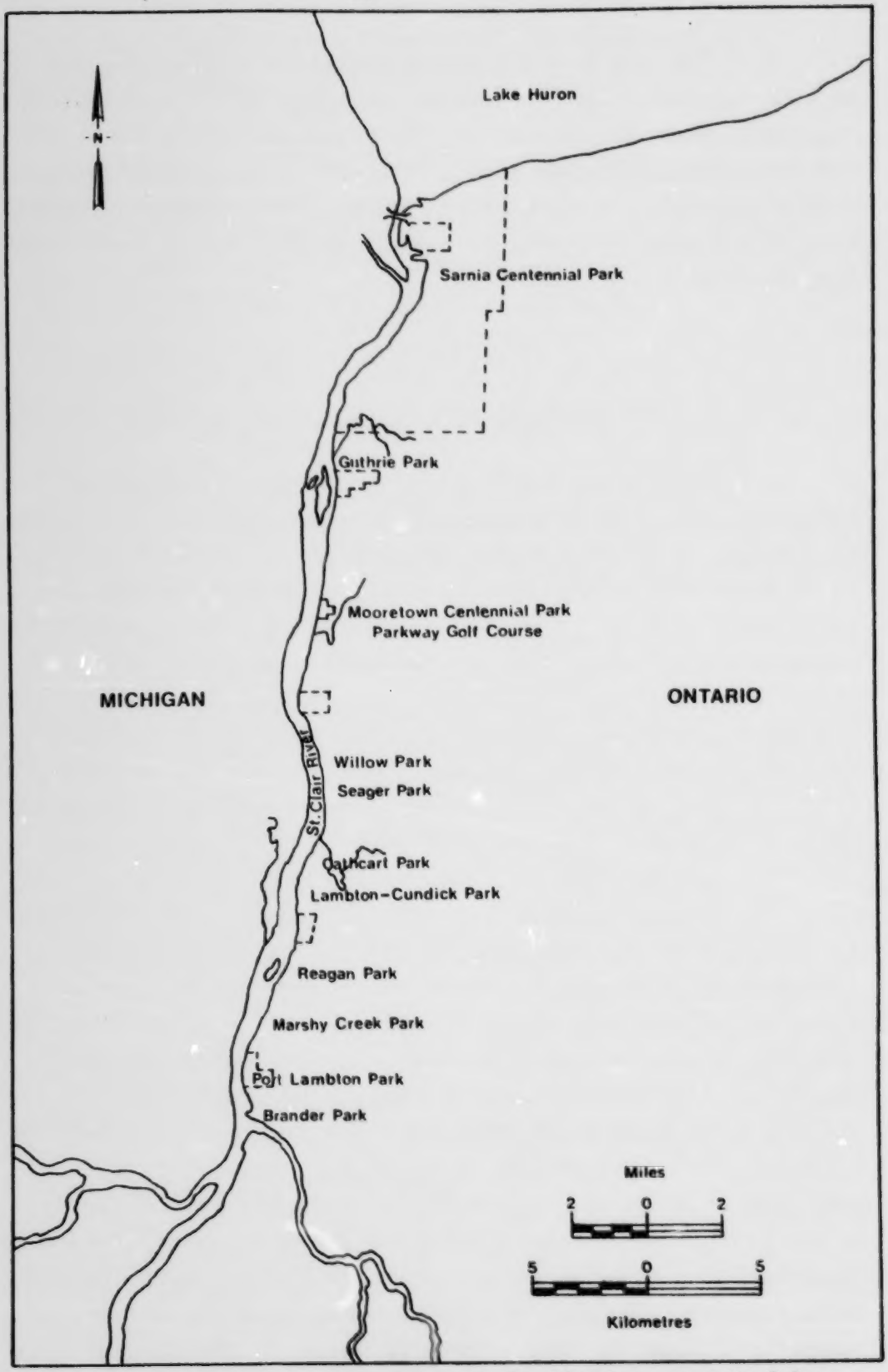


Figure 4. Parks and recreational facilities operated by the St. Clair Parkway Commission.

The St. Clair River supports an attractive and heavily utilized sport fishery. A total of 75 species of fish have been documented in the river including brown trout, splake, rainbow trout, chinook salmon, coho salmon, yellow pickerel, yellow perch, white bass, largemouth bass, smallmouth bass, channel catfish, northern pike, muskellunge and sturgeon.

SCOPE OF FIELD SURVEYS AND SURVEY METHODS - 1968 AND 1977

Biological evaluations of the St. Clair River began in 1968 with the onset of an intensive sampling program by the Ontario Water Resources Commission. Periodic sampling was undertaken subsequently to collect sediments for mercury and PCB analyses. A second intensive biological survey was conducted in 1977 by the Ontario Ministry of the Environment. The principal thrust of both biological investigations was the collection and analysis of bottom fauna (macroinvertebrates). Samples of sediments were collected in 1969 and 1977, while samples of aquatic plants, bacterial slimes and water were also collected in 1977.

Macroinvertebrates were collected at 69 locations in 1968 and at 60 locations in 1977 using a Ponar dredge operated by an electrically driven power winch (Plate 3). These locations were sampled twice in 1977 - once during the May-June period and once during the July-August period. Sampling in 1968 was conducted only once, in August. The locations of biological sampling locations were similar for both the 1968 and 1977 surveys and are shown in Figure 3. From two to five samples of bottom sediment were collected at each station for the identification and quantification of benthic macroinvertebrates. Additional sites were located in nearshore Canadian waters to investigate the effects of specific industrial shoreline discharges. The samples were

Plate 3. Survey boat and power winch.

sieved through a screen pail (0.082 mm mesh), sorted and stored in 70 percent alcohol at a mobile field laboratory (Plate 4). The samples were then transported to the main field laboratory at the Lambton Area Water Supply System for final enumeration and identification. The organisms were then preserved on slides (midges and worms) or in 95 percent alcohol.

To facilitate the analysis of macroinvertebrate species data, the river was arbitrarily divided into four major sections based on water use. Section A was defined as the section upstream from the concentration of Canadian industry. Section B included that portion of the river receiving the heaviest concentration of industrial effluents. Sections C and D were located downstream from the area of the river used most heavily as a receiver of industrial effluents. The analysis of the river within these sections was accomplished through an interpretation of species numbers and variety.

In addition to the species analysis, benthic macroinvertebrates were analysed on a community level. Such an analysis was accomplished through the use of a number of statistical procedures. The first analysis procedure involved a reduction of the 94 taxa documented in the river, using a ranking procedure after Orloci (1973). Organisms were ranked using a dispersion criterion which calculated each taxon's portion of the total community dispersion and thereby each taxon's relative importance (information). The remaining taxa were then subjected to a multivariate association (cluster) analysis after Williams and Lambert (1959), producing species associations. The association distribution was mapped and clustering of associations interpreted using an analysis of variance, the Student-Newman-Keuls (SNK) test and the test of independence to define differences in sediment and water quality among the associations as an explanation

Plate 4. Sample preparation at mobile field laboratory.

for the clustering. A relative tolerance to pollution was assigned to the associations based on these differences. This yielded the definition of zones of water quality based on association distribution and their assigned tolerances to pollution.

The occurrence of vascular aquatic plants was noted in the early summer during dredging activities. Later in the summer when plant growth had peaked, the distribution of major beds of growth was mapped and specimens were collected for identification. No samples of algal phytoplankton or periphyton were collected. Sampling for bacteria was associated with sediment analysis.

Sediments at biological sampling locations received quantitative analyses for solvent extractables, loss-on-ignition, numbers of heterotrophic bacteria, PCBs and mercury. For each dredge haul the presence of oils or greases, aquatic plants, petrochemical odours and bacterial slime growths was recorded along with a description of sediment texture and composition. Sediments from industrial sites sampled in 1977 were analysed for heavy metals to permit comparison with information obtained in 1969.

Samples of surface water were collected at all biological sampling locations on May 10, May 31, June 21, July 12, August 9 and August 30, 1977. These waters were analysed for hardness, alkalinity, pH, total and soluble phosphorus, free ammonia, total Kjeldahl nitrogen, nitrite and nitrate nitrogen, total and suspended solids, total carbon, inorganic carbon, chloride and conductivity. On July 12, samples were collected for the analysis of vinyl chloride.

On August 9, 1977, samples of water were collected from industrial sampling sites one metre from the bottom and were analysed for total and suspended solids, free ammonia, total Kjeldahl nitrogen, nitrite and nitrate nitrogen, total and soluble phosphorus, total carbon, inorganic carbon, hardness, alkalinity, phenols and pH.

All water and sediment data were statistically analysed to detect relationships with macroinvertebrate associations.

RESULTS[a] AND CONCLUSIONS

BOTTOM FAUNA

Figures 5, 6 and 7 present the average number of taxa per station and the average number of organisms per M^2. Table 4 presents a taxa list of macroinvertebrate organisms documented during the 1977 survey. A detailed taxa list for July - August, 1977 can be found in Appendix 1.

These figures clearly indicate the consistency in the variety and numbers of aquatic organisms (macroinvertebrates) along the American shoreline as compared with the disrupted state of benthic invertebrate communities along the Canadian shoreline. Although both variety and numbers of organisms are significant in the analysis of macroinvertebrate benthos, the degree of variability in community structure is a more meaningful indicator of water quality. Invertebrate

[a] Not all of the data collected are included in this report. These data are available, however, on written request to the London Regional Office of the Ontario Ministry of the Environment.

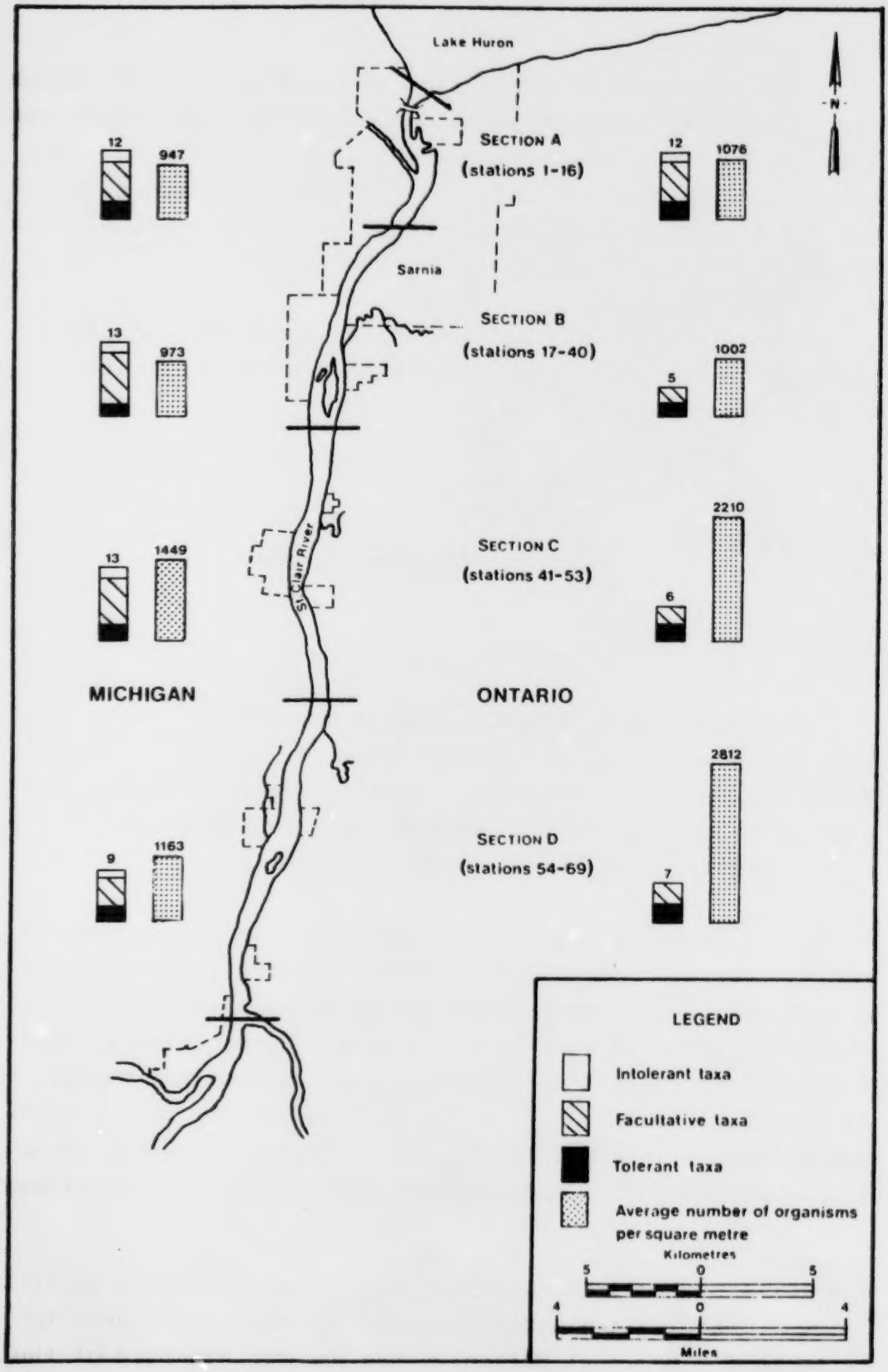


Figure 5. Average number of taxa per station and organisms per M^2 in four major sections of the St. Clair River, August, 1968.

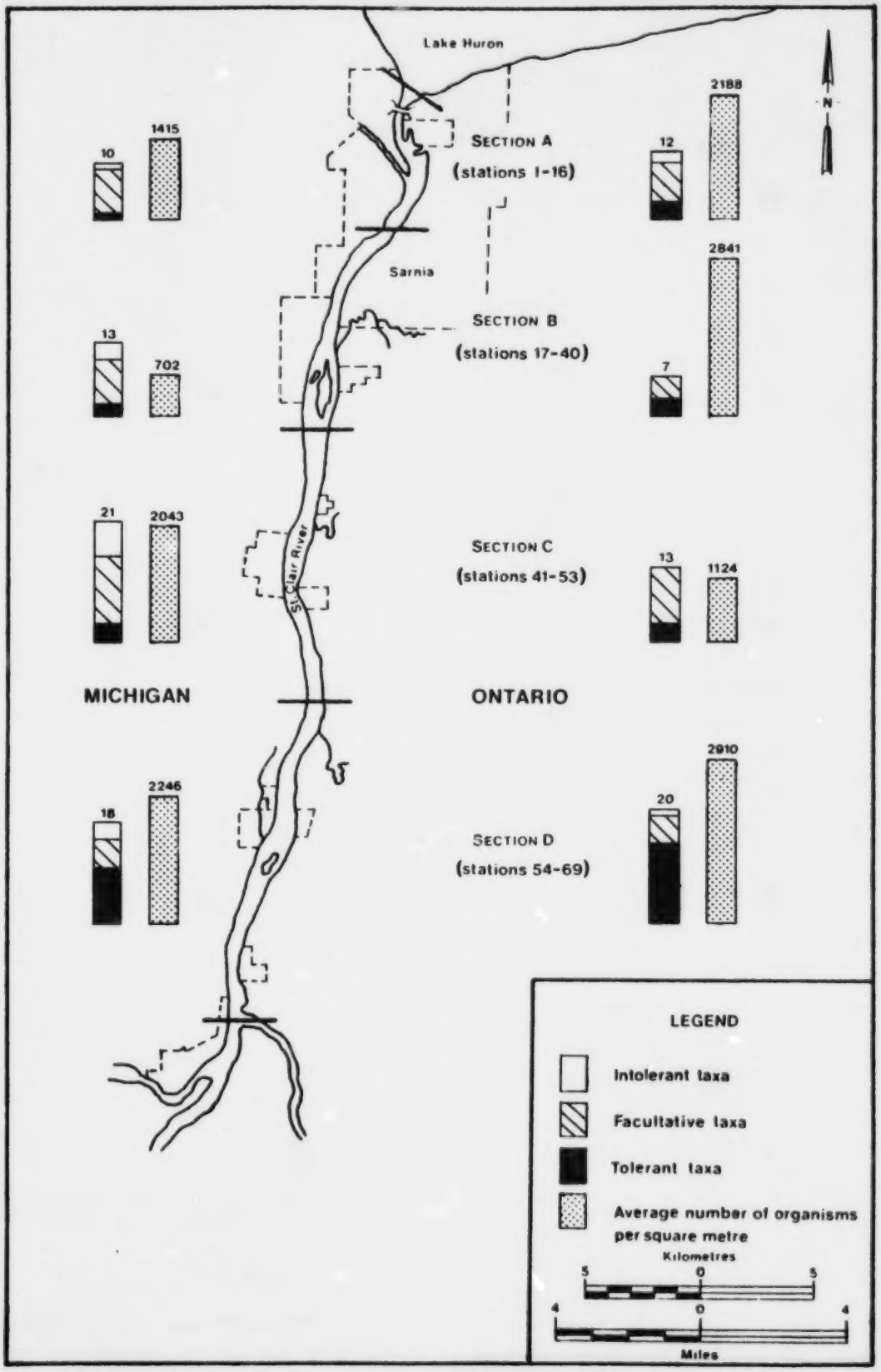


Figure 6. Average number of taxa per station and organisms per M^2 in four major sections of the St. Clair River, May - June, 1977.

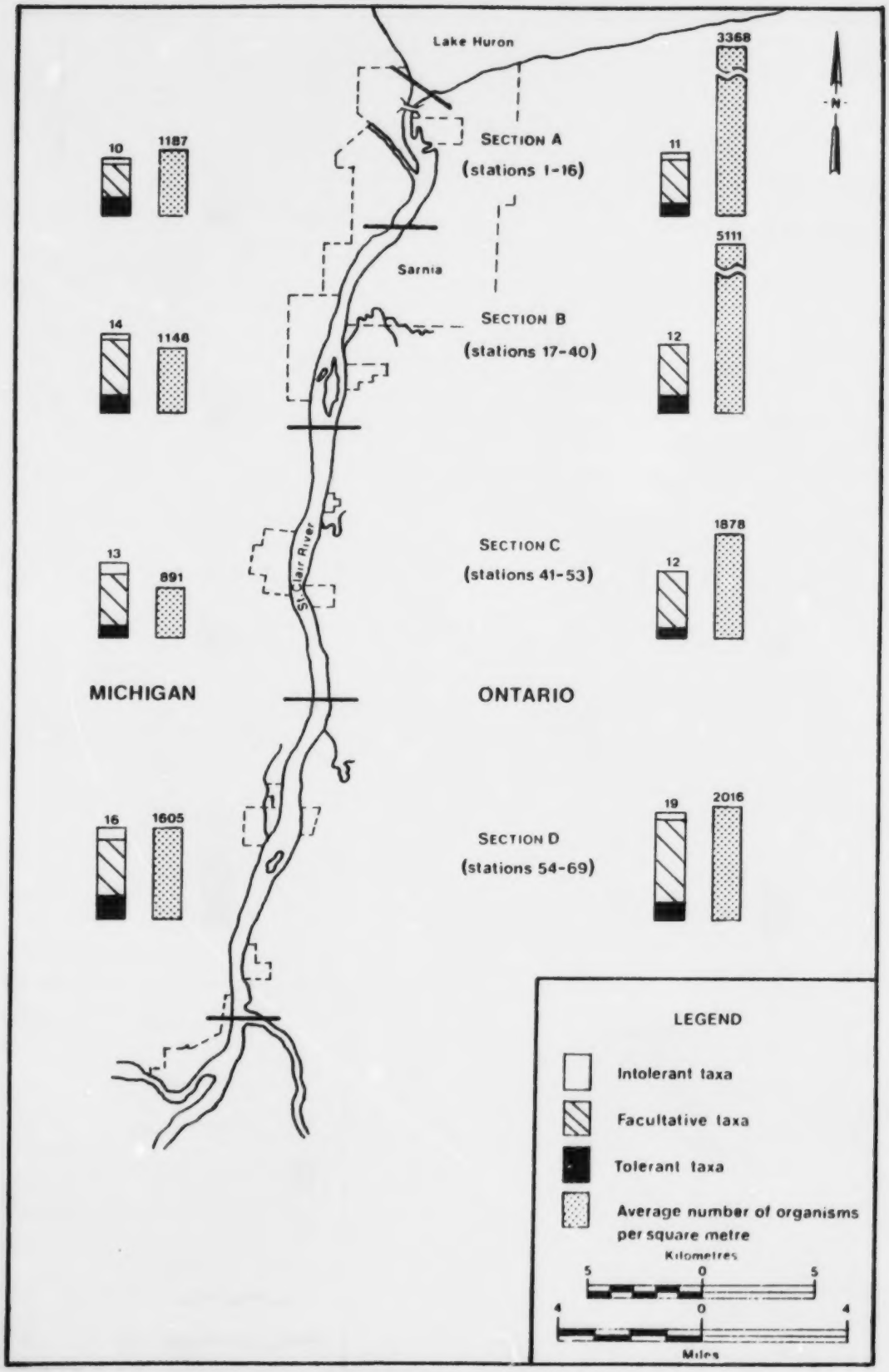


Figure 7. Average number of taxa per station and organisms per M^2 in four major sections of the St. Clair River, July - August, 1977.

Table 4. Macroinvertebrates collected in the St. Clair River during 1977.

PLECOPTERA (Stoneflies)

Perlesta placida

EPHEMEROPTERA (Mayflies)

Baetis
Caenis
Ephemerella
Hexagenia limbata
Pseudocloeon
Stenonema

TRICHOPTERA (Caddisflies)

Agraylea
Athripsodes
Brachycentrus
Cheumatopsyche
Hydropsyche
Oecetis
Polycentropus
Pycnopsyche
Pupae (unidentified)

LEPIDOPTERA (Aquatic Caterpillars)

Elophila

ODONATA (Dragonflies, Damselflies)

Gomphus

HEMIPTERA (True Bugs)

CORIXIDAE
Adult (unidentified)

COLEOPTERA (Beetles)

ELMIDAE

HYDRACARINA (Water Mites)

AMPHIPODA (Scuds)

Gammarus
Hyalella azteca
Pontoporeia affinis

ISOPODA (Aquatic Sow Bugs)

Asellus

DECAPODA (Crayfishes)

Orconectes propinquus

GASTROPODA (Snails)

Amnicola
Bithinia tentactulata
Campeloma
Goniobasis
Gyraulus
Lymnaea
Physa
Pleurocera
Somatogyrus
Valvata sincera
Valvata tricarinata
Ferrissia

PELECYPODA (Clams)

Pisidium
Sphaerium

DIPTERA (True Flies)

CULICIDAE (Phantom Midges)
CERATOPOGONIDAE (Biting Midges)
RHAGIONIDAE (Snipe Flies)

CHIRONOMIDAE (Midges)
Chironominae
Chironomus
Cryptochiromonus
Dicrotendipes
Glyptotendipes
Microtendipes
Paracladopelma
Parachironomus
Paralauterborniella
Paratendipes
Phaenopsectra
Polypedilum
Stenochironomus
Stictochironomus
Tribelos
Tribe Tanytarsini
Micropsectra
Orthocladiinae
Cardiocladius
Cricotopus
Heterotrissocladius
Psectrocladius
Corynoneura
Tanypodinae
Procladius
Tribe Pentaneurini
Diamesinae
Potthastia longimanus
Monodiamesa
Pupae (unidentified)

OLIGOCHAETA (Worms)

TUBIFICIDAE

Aulodrilus americanus
A. pluriseta
Branchiura sowerbyi
Ilyodrilus templetoni
Limnodrilus angustipenis
L. cervix
L. claparedeianus
L. hoffmeisteri
L. maumeensis
L. profundicola
L. udekemianus
Peloscolex ferox
P. freyi
P. multisetosus
Potamothrix moldaviensis
Tubifex ignotus
Tubifex tubifex
Unidentified (hair chaetae absent)
Unidentified (hair chaetae present)

LUMBRICULIDAE

Stylodrilus heringianus

NAIDIDAE

Nais bretscheri
N. communis
N. pseudobtusa
Ophidonais serpentina
Stylaria lacustris
Uncinais uncinata

HIRUDINEA (Leeches)

TURBELLARIA (Flatworms)

NEMATODA (Round Worms)

communities along the American shoreline were characterized by a wide variety of organisms with changes in numbers generally reflecting influences such as seasonality and substrate conditions. Organisms indicative of clean water were common along the American side of the river. The sediments often contained several mayfly larvae including the burrowing mayfly larva, Hexagenia limbata, several caddisfly larvae, a wide variety of facultative organisms and aquatic worms, the latter including various species of Peloscolex, Potamothrix and Stylodrilus heringianus.

In contrast, along the Canadian shoreline, the variety and numbers of benthic macroinvertebrates altered markedly along the river. Section A, upstream from the influences of industrial and municipal effluents, consistently contained the variety and numbers of aquatic macroinvertebrates representative of good water quality. In 1968, the impact of the many industrial discharges entering the river was evident as an average of 12 taxa per station in Section A was reduced to 5 in Section B. Organisms intolerant of pollution (mayfly, stonefly or caddisfly larvae) were virtually non-existent along the Canadian shoreline of Section B, whereas pollution-tolerant forms such as the tubificid worms, Limnodrilus cervix and Limnodrilus hoffmeisteri not only dominated but were often the only inhabitants of large areas of river bottom. Many areas of the river bottom in Section B were devoid of life in the vicinity of specific outfalls. During 1968, intolerant benthic macroinvertebrates did not successfully re-establish themselves at any of the sampling stations along the entire Canadian side of the river to Port Lambton, the farthest downstream sampling location. However, numbers of organisms consistently increased downstream indicating a lessening of toxic effects.

Although macroinvertebrate conditions were still seriously disrupted along the Canadian side of the river in 1977, conditions had definitely improved. Considerably higher numbers of organisms in Section B indicated a lessening of toxic effects. Although intolerant invertebrates were not yet present in Section B, the variety of facultative and tolerant taxa had more than doubled (compared to 1968) by the summer of 1977. The typical situation was one in which the variety of taxa per station was governed largely by facultative organisms; however, the number of organisms per station was largely influenced by tolerant taxa.

A recovery to a facultative community structure occurred in the downstream portion of Section B and continued throughout Section C. A mayfly-caddisfly community in American waters with stonefly larvae present contrasted with a snail-midge-worm community Canadian waters of Section C.

The most significant documentation in 1977 for the Canadian side of the river was the re-establishment of intolerant forms of benthic macroinvertebrates in Section D. Conditions as reflected by the macroinvertebrate benthos in this section were comparable to those on the American side of the river. In fact the average number of taxa per station along the Canadian shore was greater than along the American shore. Intolerant taxa were common in Canadian waters of Section D with mayfly larvae present at all stations, except Stations 62 and 64 which were scoured by strong currents. Despite the harsh environment at these two stations, the gravel provided habitat for caddisfly larvae and the lumbriculid worm, Stylodrilus heringianus, indicating good water and sediment quality.

In addition to the biological assessment of the variety and numbers of species, macroinvertebrate associations were analysed statistically as previously described. A total of 28 taxa were retained for the multivariate association (cluster) analysis which produced seven associations (as represented by statistical indicator species shown in Table 5). However, association 6 was rejected as it occurred at less than one percent of the sampling sites. The associations were mapped to detect any trends in the distribution.

Various physical, biological, sediment and water chemistry parameters were then compared among the associations using tests of independence, analyses of variance (ANOVA) and SNK tests to see if these parameters influenced association distribution. Those parameters which proved to be significantly different (ANOVA and SNK tests) among associations are presented in Table 6. Associations underscored by continuous or overlapping lines do not have significantly differing mean values.

Table 5. Benthic species associations developed from a multivariate assocation analysis (Williams and Lambert, 1959).

Association Number	Association composition (indicator organisms)
1	Procladius, Lymnaea
2	Procladius, Limnodrilus hoffmeisteri
3	Procladius
4	Limnodrilus hoffmeisteri, Lymnaea
5	Limnodrilus hoffmeisteri
6 [a]	Valvata tricarinata
7	Characterized by the absence of statistical indicator organisms

a - statistically rejected

Table 6. Results of Student-Newman-Keuls test of means for data collected during 1977.

PHYSICAL

Depth (metres) $F = 29.28^a$

Association No.	1	4	2	5	3	7
Mean	1.8	2.8	4.1	4.7	4.8	7.3

Sediment Grain Size (relative units) $F = 37.81^a$

Association No.	1	2	4	3	5	7
Mean	2.4	2.5	2.7	2.7	2.8	3.4

CHEMICAL

Loss on Ignition (%) $F = 7.36^a$

Association No.	7	3	2	1	5	4
Mean	3.31	3.68	4.04	4.32	4.54	5.9

[a] indicates a significant F value at $p < 0.01$

Table 6 (cont'd) Results of Student-Newman-Keuls test of means for data collected during 1977.

CHEMICAL - continued

Conductivity (umho/cm at 25°C) F= 5.84[a]

Assocation No.	3	1	4	2	7	5
Mean	222	222.7	223.5	224.5	225.3	243.6

Chloride (mg/l) F = 5.16[a]

Association No.	2	4	7	3	1	5
Mean	10.7	10.8	11.1	11.4	12.8	16.2

Vinyl Chloride (µg/l) F = 4.94[a]

Association No.	5	7	1	3	2	4
Mean	8.62	9.59	10.3	11.4	11.9	30.3

BIOLOGICAL

Heterotrophic Bacteria (numbers/ml x 10^3) F = 7.9[a]

Association No.	7	5	2	1	4	3
Mean	899.0	919.8	1163.4	1548.9	3738.9	3835.8

Diversity Index (Wilhm 1970) F=21.7[a]

Association No.	7	5	4	3	2	1
Mean	1.22	1.67	2.36	2.54	2.59	2.72

Tests of independence revealed that the occurrence of associations 2 and 5 at a site was associated with oil, grease or petrochemical odour of the sediment. The occurrence of associations 1, 2 and 4 at a site was related to the presence of aquatic plants. The occurrence of association 5 at a site was related to the presence of bacterial slime growths (Table 7).

A relative tolerance to pollution was assigned to each association based on the results of analyses of variance, SNK tests and the tests of independence (Figure 8). Both associations 5 and 2 were associated with sites where sediments revealed direct visual (grease, oil) and olfactory (petrochemical odour) evidence of petrochemical pollution. These

Table 7. Relationship of benthic associations to environmental factors.

Environmental factors	Association number					
	1	2	3	4	5	7
Presence of oil, grease and/or petrochemical odour in the sediments	ns	+	ns	ns	+	-
Presence of aquatic plants	+	+	ns	+	ns	-
Presence of bacterial slime growth	ns	ns	ns	ns	+	-

ns non-significant
\+ associated
\- independent

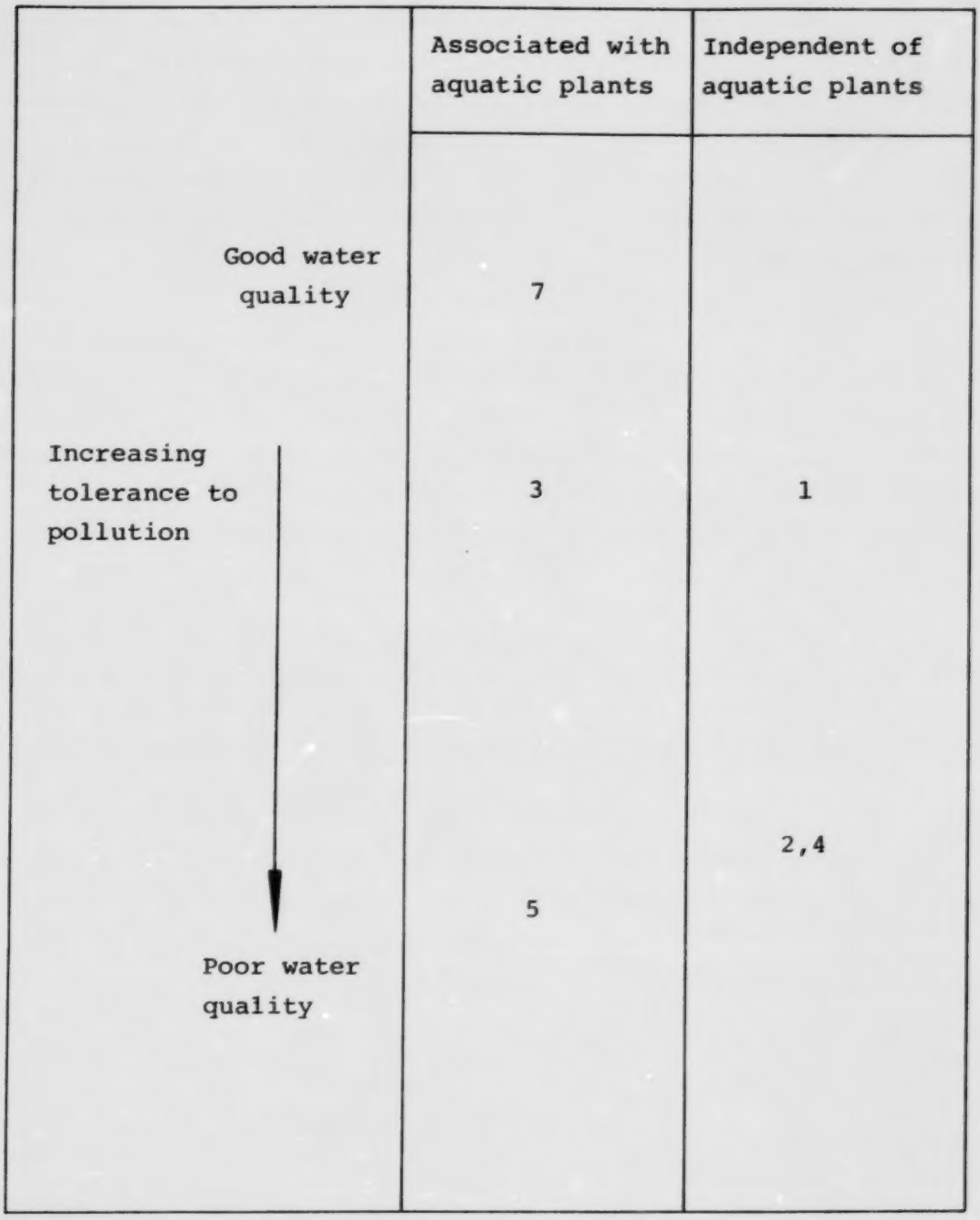


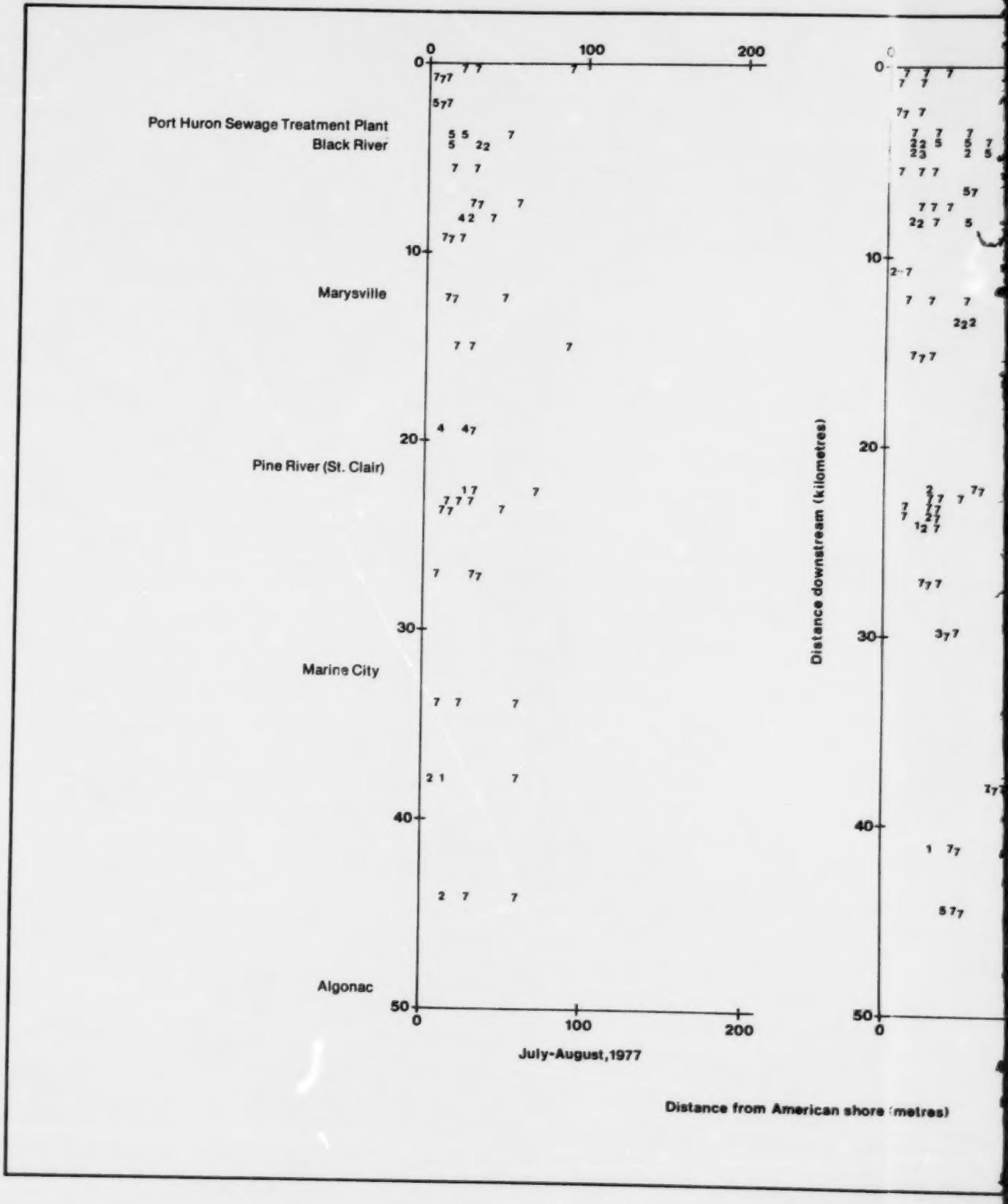
Figure 8. Pollution tolerances of benthic associations in the St. Clair River.

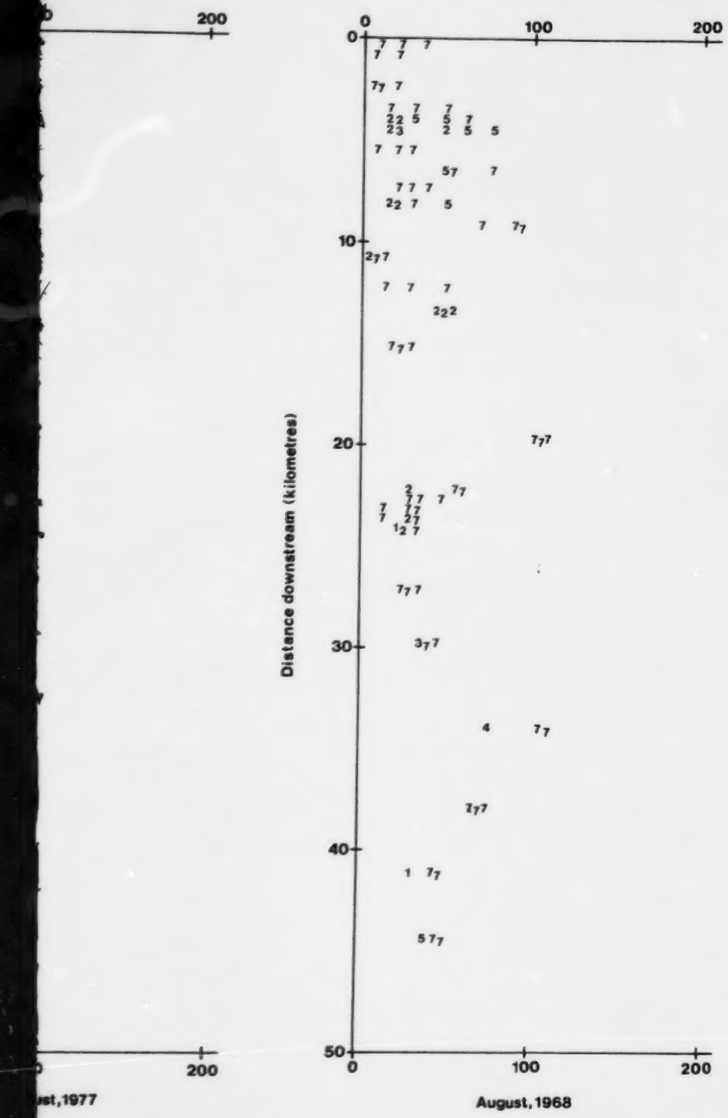
two associations were therefore judged to show the greatest tolerance to this type of pollution. Association 5 was the only association which was positively associated with bacterial slime growths. These growths are primarily a matrix of bacteria intermixed with fungi and protozoa and are typically found below discharges where organic carbon content is high and dissolved oxygen is low. Owing to the association with sewage fungus, a significantly higher conductivity, a higher concentration of chloride and a significantly lower diversity index, association 5 was judged as the most tolerant to pollution. Association 4 was found at sites with significantly higher concentrations of vinyl chloride and other organic compounds as indicated by a higher loss-on-ignition value in the sediments. Association 4 was therefore judged to be similar in pollution tolerance to association 2 which was associated with the visual presence of oils, greases and petrochemical odour. Associations 1 and 3 were found at sites with little evidence of pollution and were therefore judged to exhibit the greatest intolerance to pollution. Association 7 was found in the cleanest habitat, typically in the greater depths and coarser sediments of the shipping channel farther offshore. Associations 1, 2 and 4 were found to be associated with aquatic plant growth in the river. Increases in the occurrences of associations 1 and 4 (both containing the snail Lymnaea) from spring to summer probably reflected the increase in plant growth.

Following the mapping of the species associations (Figure 9) the river was then divided into zones of water quality (Figure 10) based on association distribution and their assigned tolerances to pollution. Definition of the zones of water quality was based primarily on the distribution of association 5. Clean-water zones were characterized by the virtual absence of association 5. Zones of serious

water quality impairment were characterized by the dominance of association 5 indicating that these areas of the river were the most heavily polluted. Zones of partial recovery were characterized by the presence of association 5 intermixed with associations 2 and 4. A zone of further recovery of water quality was characterized by the virtual disappearance of association 5 and the appearance of associations 1 and 3, the most pollution intolerant associations. Such a composition of associations indicated that this zone of the river had virtually recovered from upstream pollutional impacts. The distribution of association 7 along the river generally reflected the greater depths and swifter currents (coarser sediments) of the shipping channel.

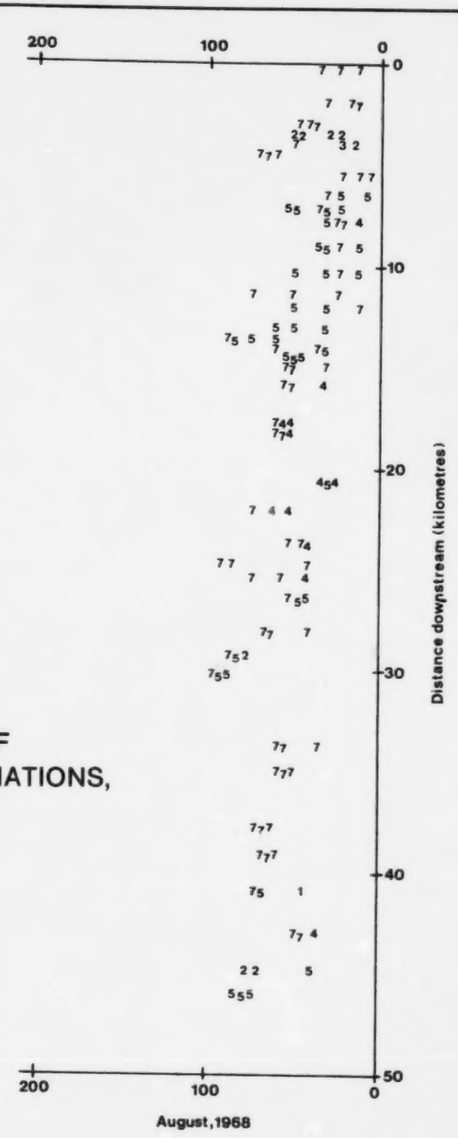
By reference to Figure 10, differences in water quality can be seen by comparing association distributions in 1968 and 1977. In 1977 a zone of recovery was present along the Canadian shoreline. As discussed earlier, a detailed analysis of the community structure within this zone indicated that complete recovery of the benthos had in fact occurred. The benthos of the Canadian shoreline in this zone was comparable to the benthos of the relatively unpolluted American shoreline. No such recovery was evident in 1968. It can also be seen that the extent of the zone of serious impairment had decreased markedly in 1977.


Port Huron Sewage Treatment Plant
Black River
Marysville
Pine River (St. Clair)
Marine City
Algonac
0
100
200
10
20
30
40
50
Distance downstream (kilometres)
July-August, 1977
Distance from American shore (metres)

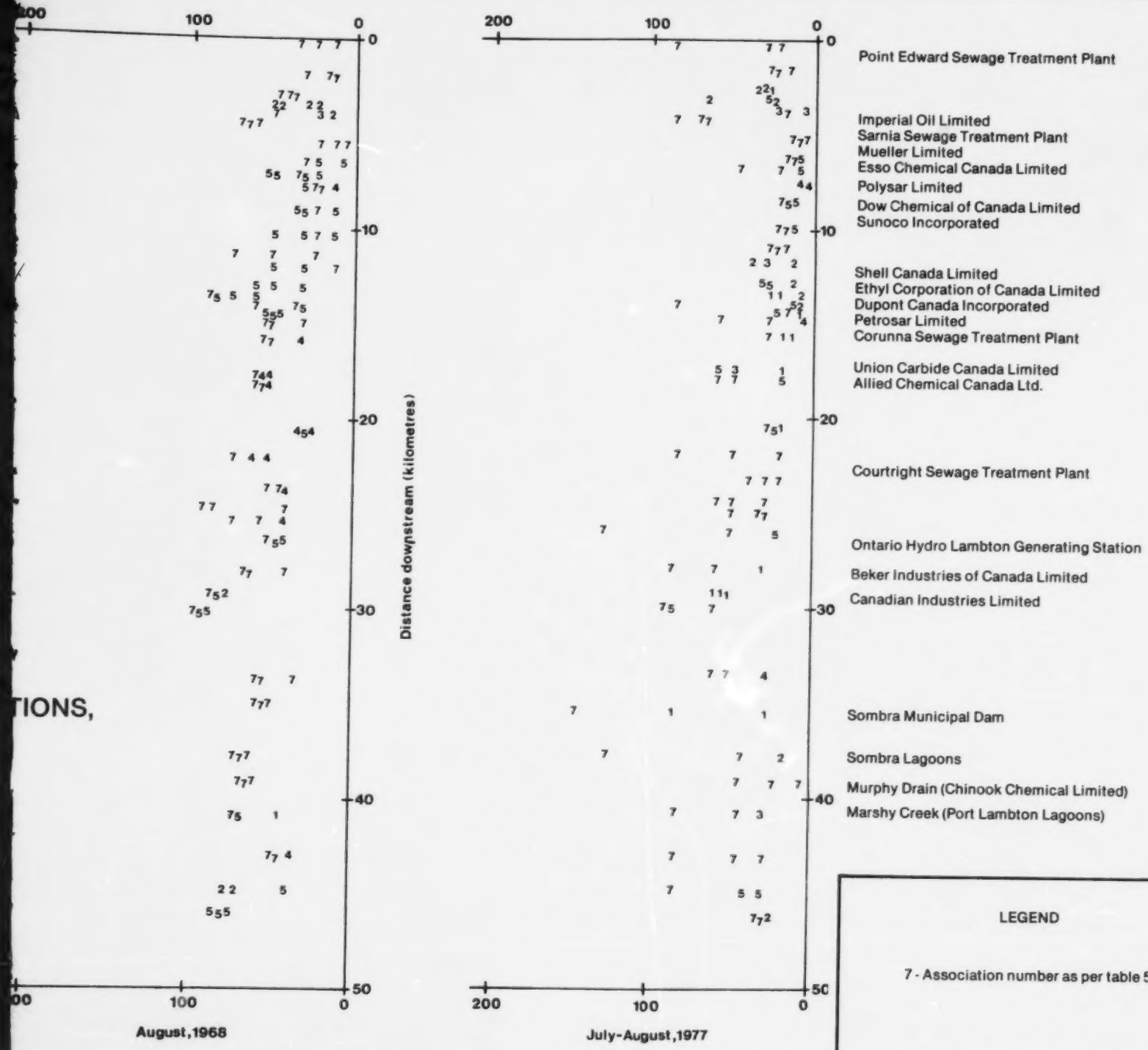


Distance from American shore (metres)

DISTRIBUTION OF BENTHIC ASSOCIATIONS, 1968 AND 1977.



Distance from Canadian shore (metres)


200
100
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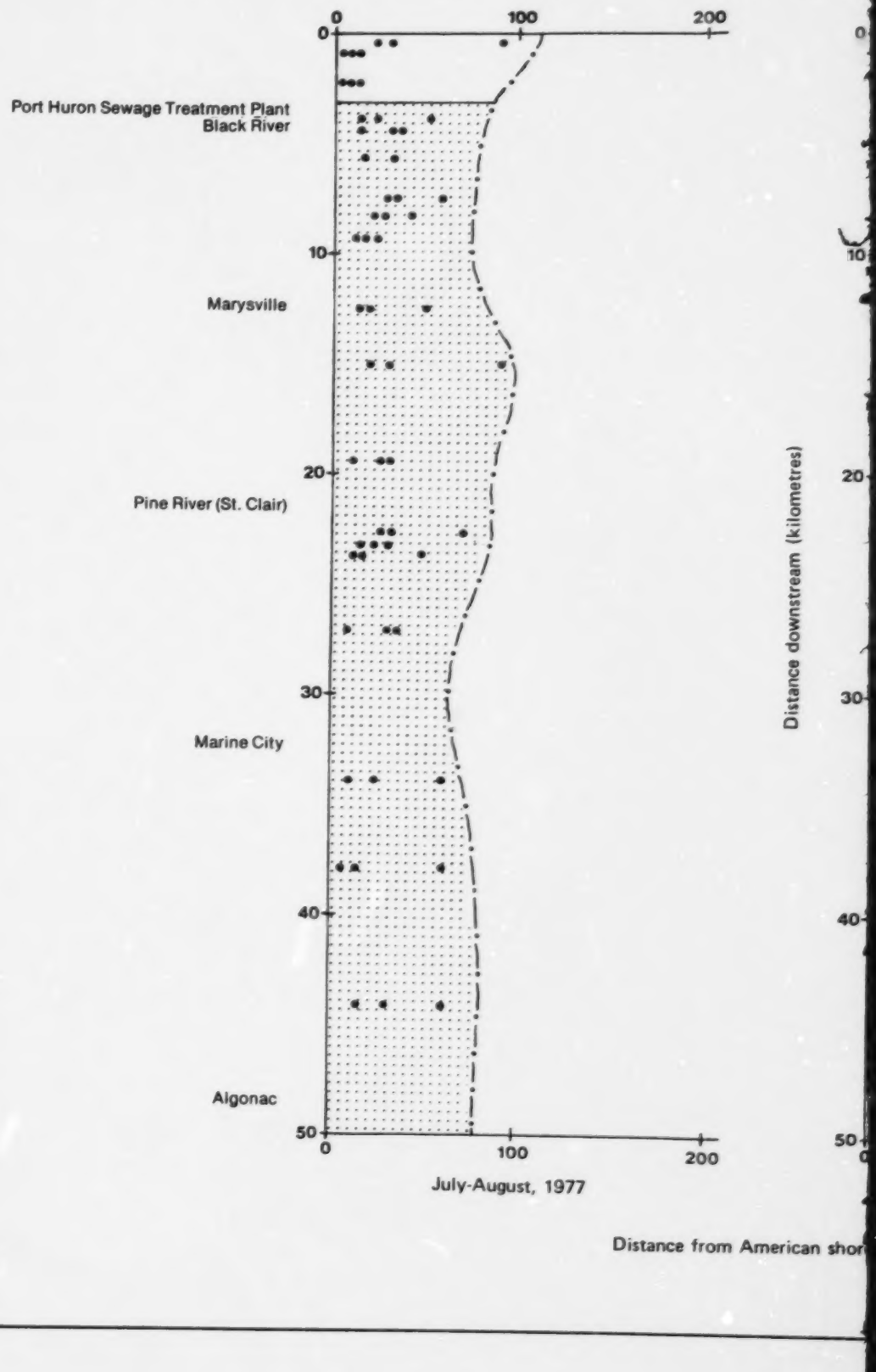
0
10
20
30
40
50
Distance downstream (kilometres)
August, 1968
July-August, 1977
Distance from Canadian shore (metres)
Point Edward Sewage Treatment Plant
Imperial Oil Limited
Sarnia Sewage Treatment Plant
Mueller Limited
Esso Chemical Canada Limited
Polysar Limited
Dow Chemical of Canada Limited
Sunoco Incorporated
Shell Canada Limited
Ethyl Corporation of Canada Limited
Dupont Canada Incorporated
Petrosar Limited
Corunna Sewage Treatment Plant
Union Carbide Canada Limited
Allied Chemical Canada Ltd.
Courtright Sewage Treatment Plant
Ontario Hydro Lambton Generating Station
Beker Industries of Canada Limited
Canadian Industries Limited
Sombra Municipal Dam
Sombra Lagoons
Murphy Drain (Chinook Chemical Limited)
Marshy Creek (Port Lambton Lagoons)
LEGEND
7 - Association number as per table 5

TIONS,

Figur


0
100
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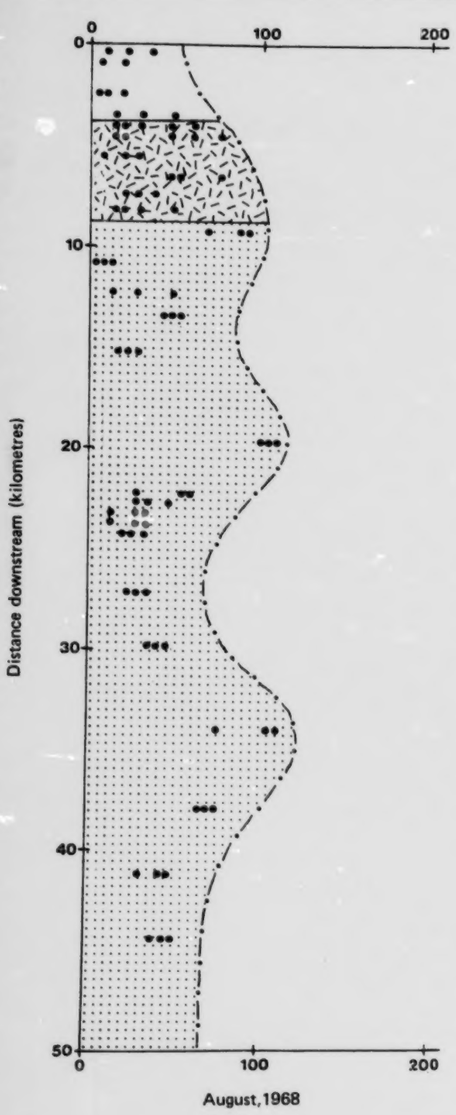
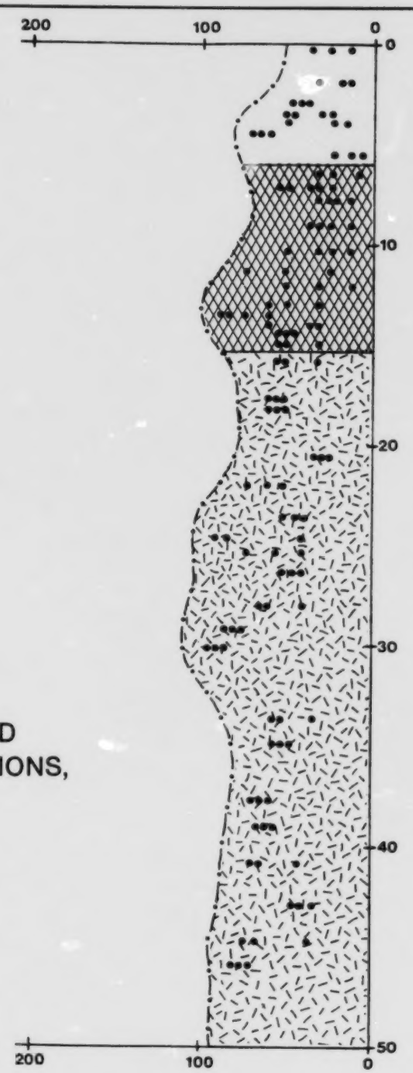
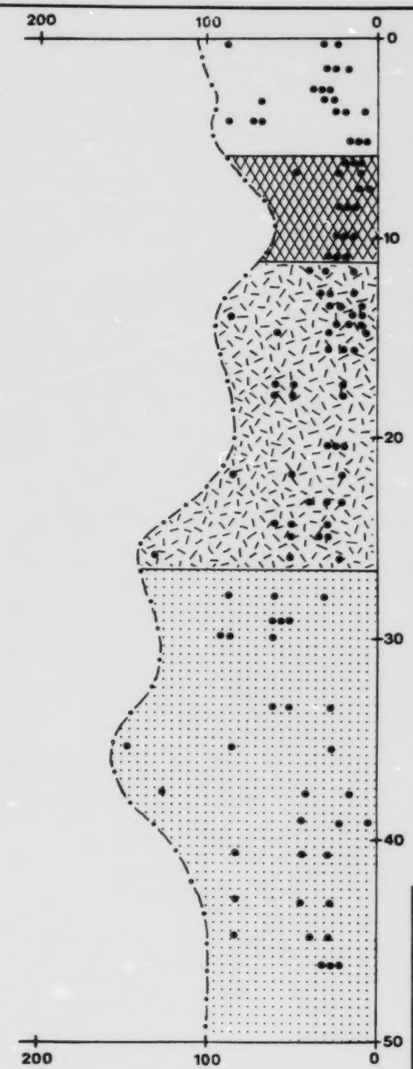
Port Huron Sewage Treatment Plant
Black River
10
Marysville
20
Pine River (St. Clair)
30
Marine City
40
Algonac
50
Distance downstream (kilometres)
July-August, 1977
Distance from American shor



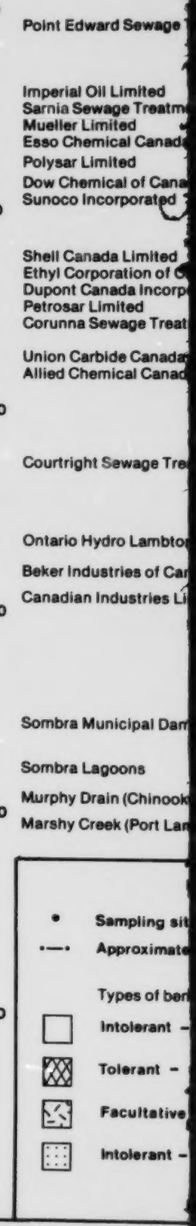
merican shore (metres)

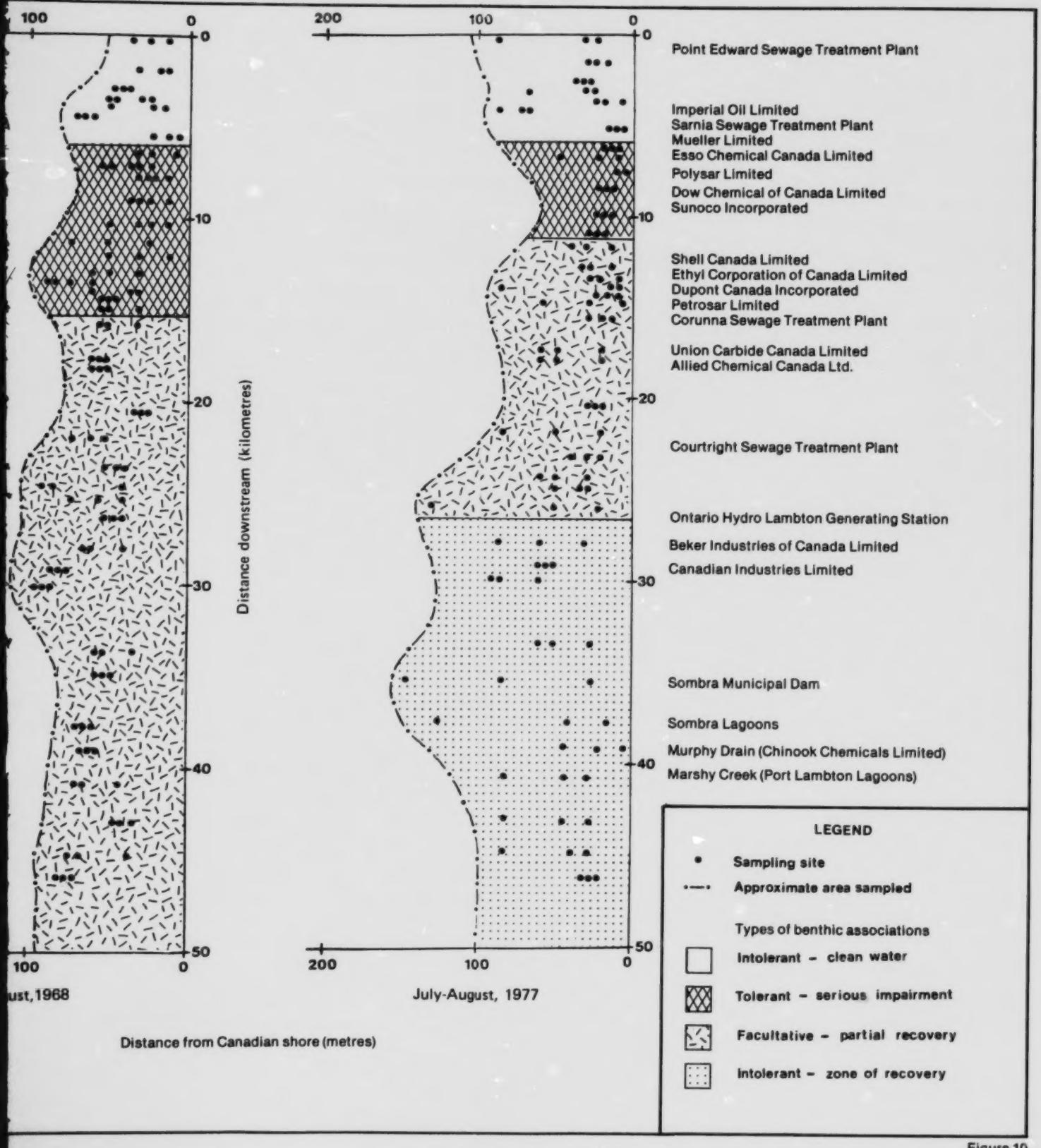
WATER QUALITY AND BENTHIC ASSOCIATIONS, 1968 AND 1977.





Distance from Canadian shore (metres)




100
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ust, 1968
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10
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40
50
200
100
0
July-August, 1977
Distance downstream (kilometres)
Distance from Canadian shore (metres)
Point Edward Sewage Treatment Plant
Imperial Oil Limited
Sarnia Sewage Treatment Plant
Mueller Limited
Esso Chemical Canada Limited
Polysar Limited
Dow Chemical of Canada Limited
Sunoco Incorporated
Shell Canada Limited
Ethyl Corporation of Canada Limited
Dupont Canada Incorporated
Petrosar Limited
Corunna Sewage Treatment Plant
Union Carbide Canada Limited
Allied Chemical Canada Ltd.
Courtright Sewage Treatment Plant
Ontario Hydro Lambton Generating Station
Beker Industries of Canada Limited
Canadian Industries Limited
Sombra Municipal Dam
Sombra Lagoons
Murphy Drain (Chinook Chemicals Limited)
Marshy Creek (Port Lambton Lagoons)
LEGEND
Sampling site
Approximate area sampled
Types of benthic associations
Intolerant - clean water
Tolerant - serious impairment
Facultative - partial recovery
Intolerant - zone of recovery

Figure 10

AQUATIC PLANTS

Aquatic plant development in 1977 had increased substantially compared with growths noted in 1968-69. For this reason, a documentation of major plant species and their distribution was completed to establish a baseline for future comparisons. In addition, the presence or absence of aquatic plants was noted in each dredge haul. It was anticipated that such a documentation would assist in assessing the distribution of macroinvertebrate associations, which in fact did result as associations 1, 2 and 4 were shown to be associated with the presence of aquatic plants. Where suitable substrate was present, it was observed that beds of aquatic plants were generally associated with specific industrial outfalls, as well as with the mouths of tributary streams and other depositional zones (Figure 11).

More specifically, Sarnia Bay (a depositional area) had heavy growths of the alga, Chara, pondweeds, Canada waterweed and Eurasian milfoil. Offshore from Imperial Oil Limited profuse growths of the pondweed, Potamogeton-richardsonii, extended in a 50-metre wide continuous bed to Station 20. This surface mat was thick enough to prevent the passage of the survey boat (Plate 5). Severe growths of the pondweeds, Potamogeton pectinatus and P. richardsonii, extended along the entire shoreline of Polysar Limited. No algae or aquatic plants were present along the entire shoreline of Dow Chemical of Canada Limited where a heavy crust of a white calcium precipitate covered large areas of the bottom and prevented growth. The next area of heavy growth was offshore from the mouth of Talford Creek (Shell Canada Limited). These growths were dense and comprised of several pondweeds, the beds extending downstream to Station 34. The shallow, sandy shoals around Stag Island supported a variety of aquatic plants (mostly pondweeds) and large surface mats were present in the bay on the northwest side of the island.

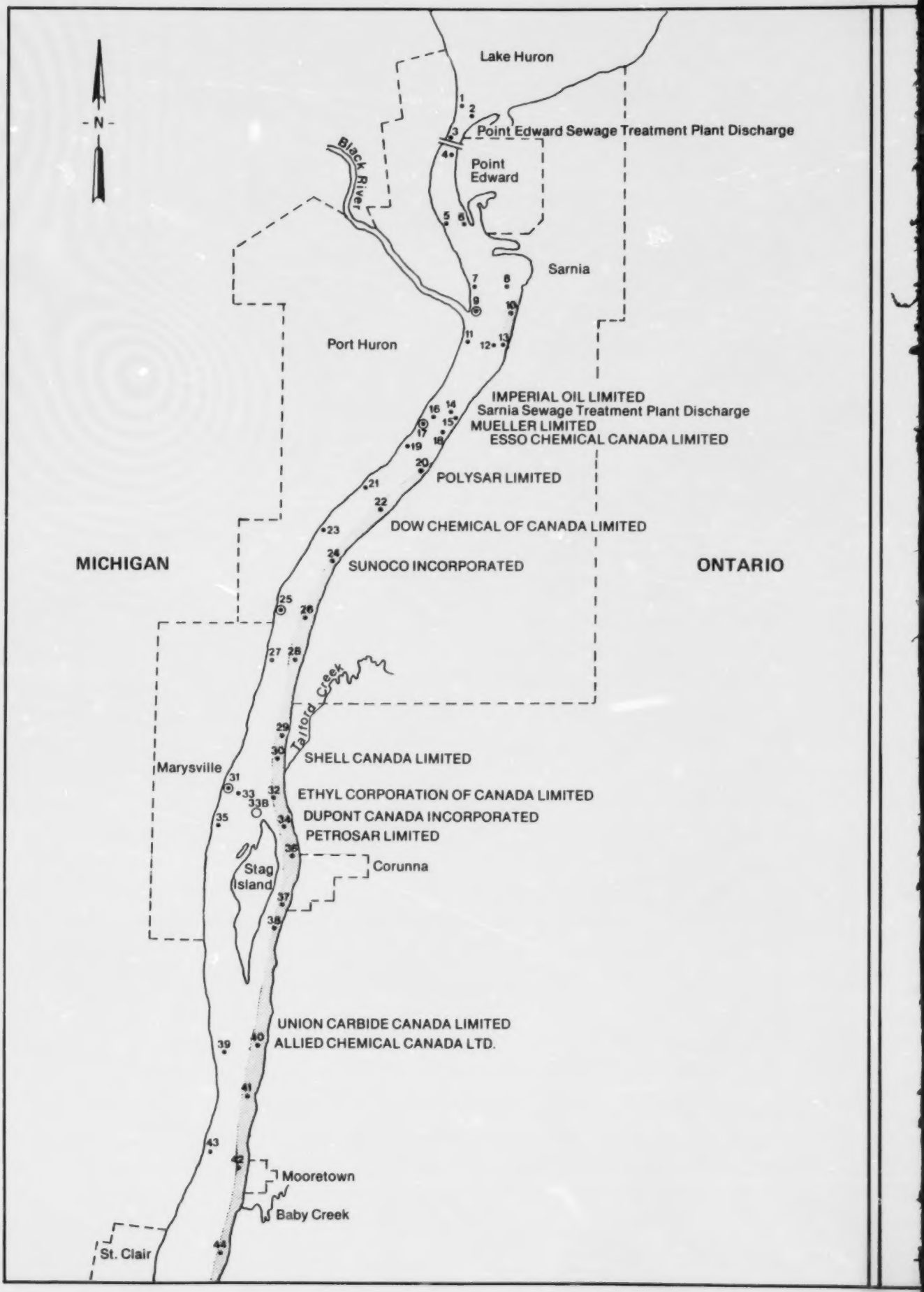
Large mats of Potamogeton praelongus and P. richardsonii, grew in a nearshore zone approximately 10 metres in width from Dupont Canada Incorporated (Station 34) to Station 37. The filamentous alga, Cladophora, was observed frequently in this area, growing on breakwalls and dock structures.

Downstream from Stag Island, plant growths were confined to a narrow nearshore band along the Canadian shoreline. Localized areas of heavier growth were documented downstream from Allied Chemical Canada Ltd., the Ontario Hydro-Lambton Generating Station and areas near Woodtick Island.

BACTERIAL SLIME GROWTHS

Extensive areas of the St. Clair River were fouled by growths of filamentous bacteria identified as members of the Clamydobacteriaceae (the sheathed bacteria).

During the May-June sampling period, bacterial slime growths were retrieved in all dredge hauls from Station 20 offshore from Polysar Limited to Station 52, downstream from the Lambton Generating Station (Figure 12). In addition, all visible substrates through this reach (dock structures, breakwalls and aquatic plants) were coated with the slime (Plate 6). From these observations it was concluded that the slime growths were virtually continuous over the 32-kilometre distance from Station 20 to Station 52 and that the growths extended from the shoreline outward to the edge of the shipping channel where growth conditions became unsuitable because of the strong current.


Lake Huron
N
Point Edward Sewage Treatment Plant Discharge
Point Edward
Black River
Sarnia
Port Huron
IMPERIAL OIL LIMITED
Sarnia Sewage Treatment Plant Discharge
MUELLER LIMITED
ESSO CHEMICAL CANADA LIMITED
POLYSAR LIMITED
DOW CHEMICAL OF CANADA LIMITED
MICHIGAN
SUNOCO INCORPORATED
ONTARIO
Talford Creek
Marysville
SHELL CANADA LIMITED
ETHYL CORPORATION OF CANADA LIMITED
DUPONT CANADA INCORPORATED
PETROSAR LIMITED
Stag Island
Corunna
UNION CARBIDE CANADA LIMITED
ALLIED CHEMICAL CANADA LTD.
Mooretown
Baby Creek
St. Clair

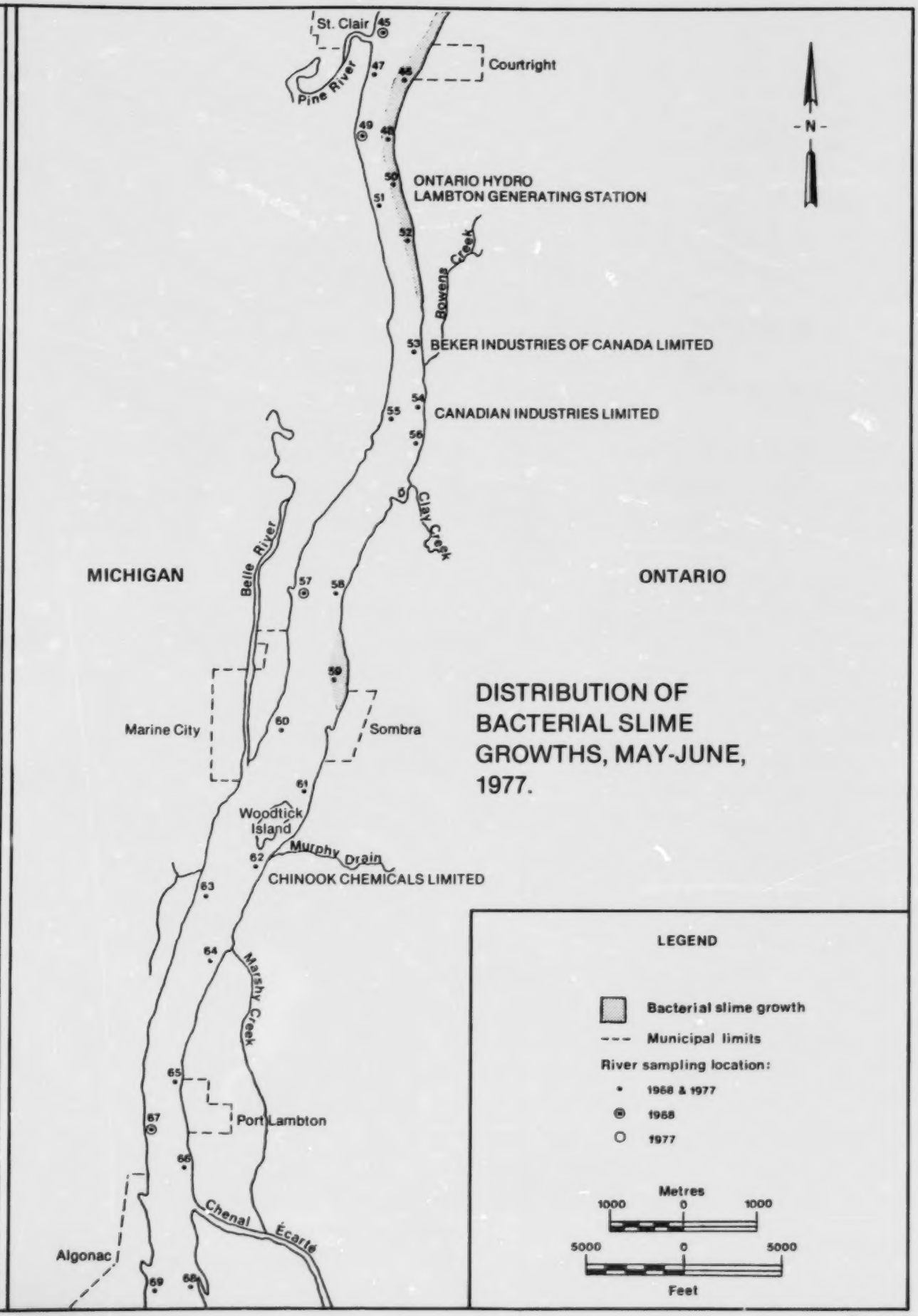

St. Clair
45
Courtright
Pine River
47
48
49
50
ONTARIO HYDRO
LAMBTON GENERATING STATION
51
52
Bowens Creek
53
BEKER INDUSTRIES OF CANADA LIMITED
54
55
CANADIAN INDUSTRIES LIMITED
56
Clay Creek
Belle River
MICHIGAN
ONTARIO
57
58
59
Marine City
60
Sombra
61
Woodtick Island
Murphy Drain
62
CHINOOK CHEMICALS LIMITED
63
64
Marshy Creek
65
Port Lambton
67
66
Chenal Écarté
Algonac
69
68
N
DISTRIBUTION OF BACTERIAL SLIME GROWTHS, MAY-JUNE, 1977.
LEGEND
Bacterial slime growth
Municipal limits
River sampling location:
1968 & 1977
1968
1977
Metres
1000
0
1000
5000
0
5000
Feet

Figure 12

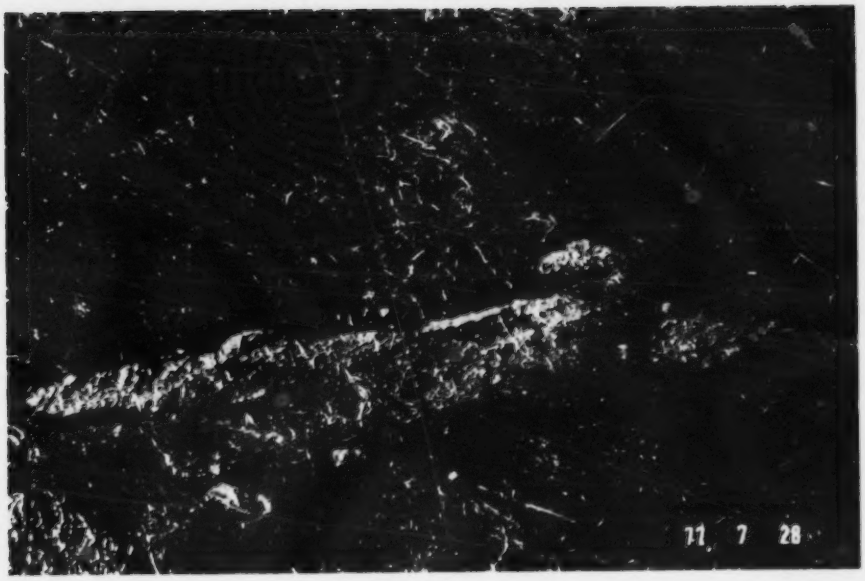


Plate 5. Heavy growths of rooted aquatic plants.

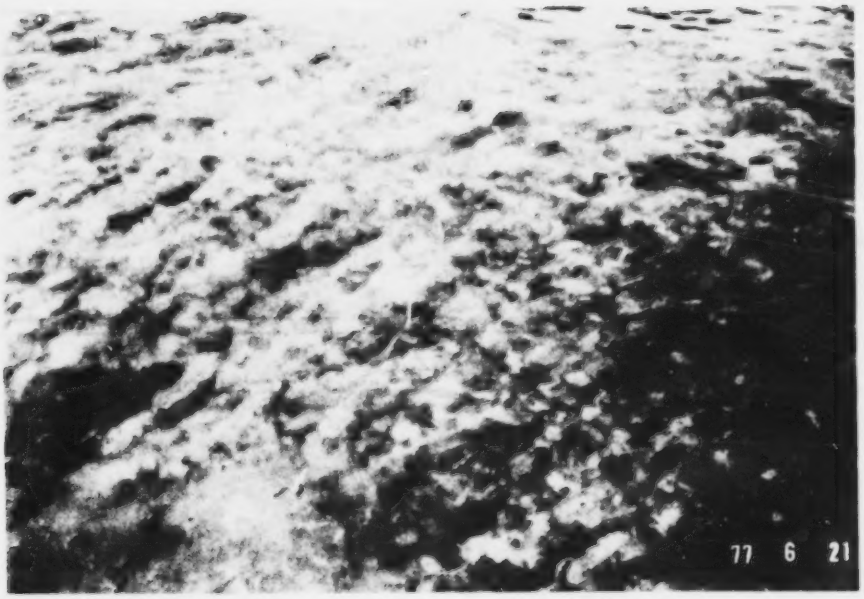


Plate 6. Bacterial slimes growing on rooted aquatic plants.

Later in the summer during the July-August sampling period, the bacterial slime growths were observed to be thriving only in the immediate vicinity of specific outfalls. These bacteria were viewed microscopically and although not identified it was noted that the growths were mostly composed of a single species as compared to the more mixed communities observed earlier. Although localized, these growths were profuse and sloughed filaments were noted to have fouled downstream areas, (sediments downstream from these growth areas were covered with a layer of decomposing filaments). During August 1977, gill nets set 100 metres downstream from the Imperial Oil Limited - #9 separator discharge were heavily fouled within two hours by drifting bacterial filaments. The inside of certain effluent pipes from Polysar Limited were coated with bacterial slime growths.

SEDIMENTS

Polychlorinated Biphenyls (PCBs)

As part of the St. Clair River investigations, sediments were analysed for PCBs in 1976, 1977 and 1978 (Table 8).

Table 8. Concentrations of PCBs (µg/kg) in surficial sediments of the St. Clair River.

Date	Sample size	Maximum	Minimum	Mean	Standard deviation
1976	26	6,800	0	748[a]	± 1710
1977	90	10,000	0	277	± 1127
1978	45	5,300	0	771[a]	± 1214

a these higher mean concentrations reflect sampling along the Canadian shoreline only.

The most comprehensive sampling was conducted in 1977 when 90 samples were collected, including samples from both sides of the river. During 1976 and 1978 samples were only collected near the Canadian shoreline.

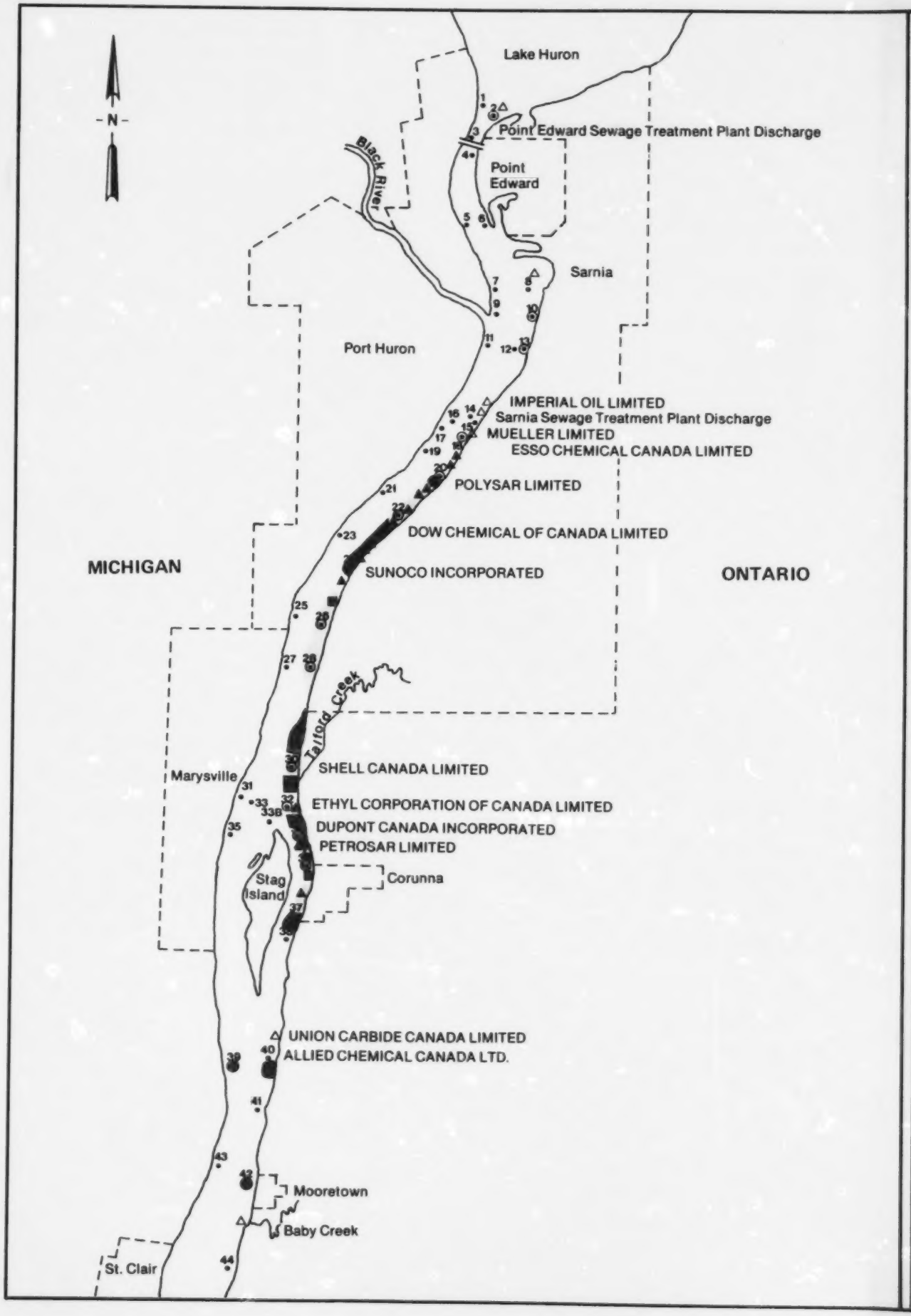
During 1977, sediments with PCB concentrations in excess of 100 µg/kg were found along both shorelines of the river. The Ministry of the Environment's Marine Construction Guideline is 50 µg/kg, above which sediments are not considered safe for disposal into an open water environment. No area of Lake Huron, the source of the St. Clair River, had concentrations in excess of 100 µg/kg (IJC, 1978). The highest concentrations of PCBs were along the Canadian shoreline and generally coincided with point-source discharges. Five stations in a reach of approximately 1.4 kilometres located offshore from Polysar Limited and Dow Chemical of Canada Limited averaged over 3,000 µg/kg and ranged as high as 10,000 µg/kg (Figure 13). Aroclor 1254 was the major PCB detected in this reach.

On all three sampling occasions, the maximum concentrations in the sediments were found in an area of river offshore from Dow Chemical of Canada Limited and elevated concentrations extended upstream to Polysar Limited. Direct discharges of PCBs to the river ceased during 1975. Further detailed sampling will be necessary to precisely determine the extent and possibly identify the source of the contaminated sediments. The consistently high concentrations of PCBs at specific locations indicates that concentrations of PCBs in the surficial sediments are not rapidly declining or translocating.

The presence of high concentrations of PCBs in the sediments of the St. Clair River is of particular concern because of the detection of PCBs in fish from the St. Clair

River and nearby Lake Huron and Lake St. Clair, at concentrations which pose a threat to human health (2,000 µg/kg). Medical specialists suggest that fish containing PCBs in excess of 2,000 µg/kg be eaten only by adults (except women of child bearing age) on an occasional meal basis as outlined in consumption guidelines (Government of Ontario publication, 1979).

Considering Lake Huron (including the westerly shore of Georgian Bay), the St. Clair River and Lake St. Clair, 9 species of fish have been identified containing in excess of 2,000 µg/kg of PCBs. These species are rainbow trout, brown trout, splake, chinook and coho salmon, smallmouth bass, white sucker, carp and gizzard shad. The high affinity of PCBs for fats is a significant factor affecting concentrations in fish. Species with a higher fat content such as salmon accumulate more PCBs than leaner fish such as walleye. However, compared to other areas of the Province, the walleye of Lake St. Clair contained unusually high concentrations of PCBs with the maximum recorded concentration (1990 µg/kg) approaching the provincial guideline (2,000 µg/kg). Two samples of gizzard shad were collected in 1977, one immediately downstream from Imperial Oil Limited (near the area of high sediment concentrations) and one in the vicinity of Stag Island (remote from the area of high sediment concentrations). The gizzard shad from the vicinity of Stag Island averaged 1435 µg/kg of PCBs ranging as high as 2580 µg/kg. The gizzard shad collected closer to the area contaminated with PCBs averaged 2580 µg/kg (in excess of the guideline) and ranged as high as 9250 µg/kg (a very high concentration). The difference in these two samples of gizzard shad may indicate that they accumulated the high levels of PCBs from sediments of the St. Clair River.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Lake Huron
Point Edward Sewage Treatment Plant Discharge
Point Edward
Black River
Sarnia
Port Huron
IMPERIAL OIL LIMITED
Sarnia Sewage Treatment Plant Discharge
MUELLER LIMITED
ESSO CHEMICAL CANADA LIMITED
POLYSAR LIMITED
DOW CHEMICAL OF CANADA LIMITED
SUNOCO INCORPORATED
MICHIGAN
ONTARIO
Talfold Creek
SHELL CANADA LIMITED
Marysville
ETHYL CORPORATION OF CANADA LIMITED
DUPONT CANADA INCORPORATED
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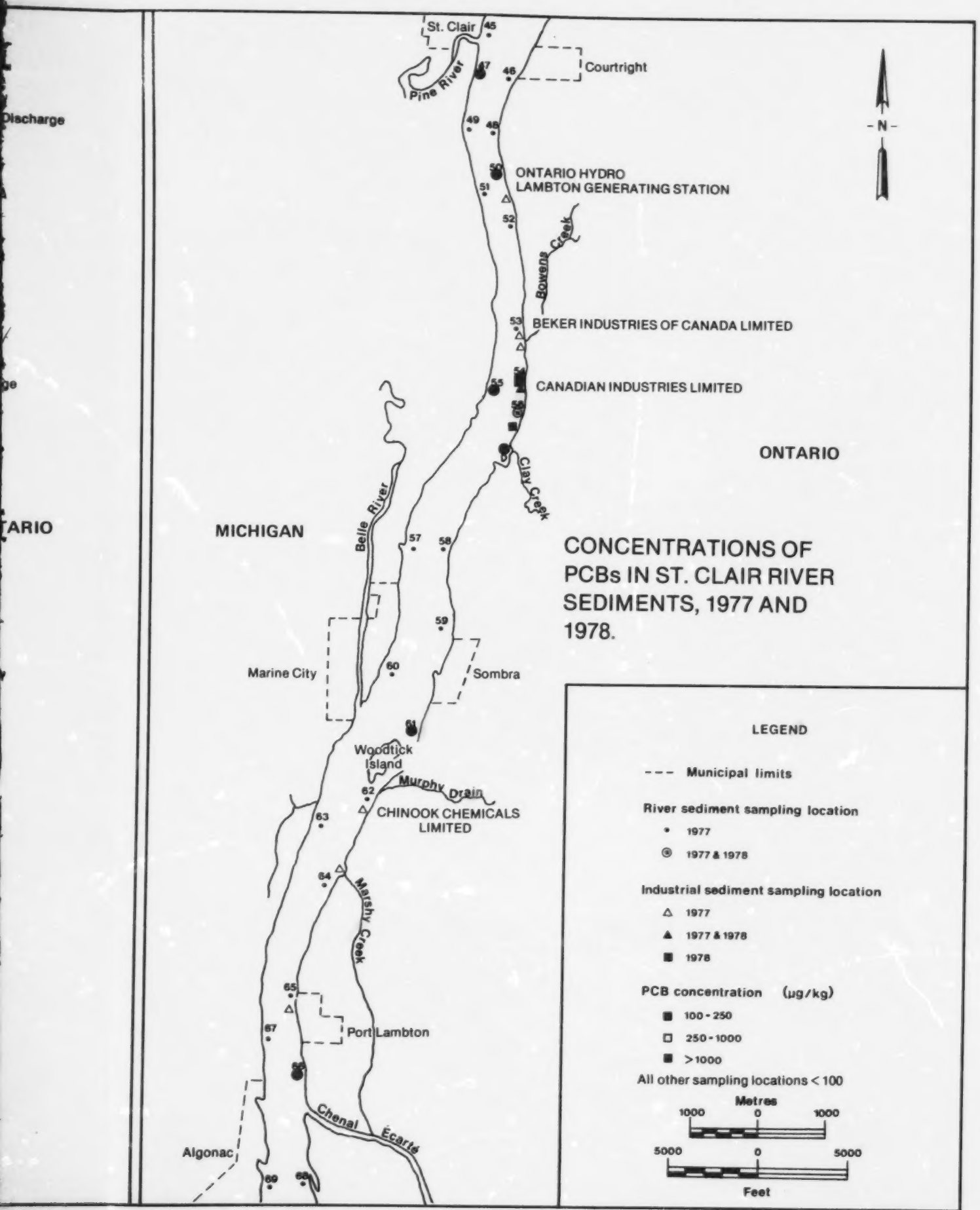
Stag Island
UNION CARBIDE CANADA LIMITED
ALLIED CHEMICAL CANADA LTD.
Mooretown
Baby Creek
St. Clair


St. Clair
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Courtright
Pine River
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ONTARIO HYDRO
LAMBTON GENERATING STATION
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Bowens Creek
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BEKER INDUSTRIES OF CANADA LIMITED
CANADIAN INDUSTRIES LIMITED
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ONTARIO
Clay Creek
MICHIGAN
Belle River
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Marine City
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Sombra
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Woodtick Island
Murphy Drain
62
CHINOOK CHEMICALS LIMITED
63
64
Marshy Creek
65
67
Port Lambton
66
Chenal Ecarté
Algonac
69
68
N
CONCENTRATIONS OF PCBs IN ST. CLAIR RIVER SEDIMENTS, 1977 AND 1978.
LEGEND
Municipal limits
River sediment sampling location
1977
1977 & 1978
Industrial sediment sampling location
1977
1977 & 1978
1978
PCB concentration (µg/kg)
100 - 250
250 - 1000
>1000
All other sampling locations < 100
Metres
1000
0
1000
5000
0
5000
Feet

Figure 13

Gizzard shad are an almost exexclusive bottom feeder and stomachs of adults often contain large quantities of mud (Scott and Crossman, 1973).

Other Organics

Through sampling observations it became obvious that the presence of organic compounds in the sediments and on the surface of the water was a common occurrence. Dredged sediments were pungent exhibiting strong petrochemical odours and some were fouled with globules of oily or tarry substances (Plate 7). The rainbow sheens of slicks were a daily observation and several major spills were documented that affected several kilometers of the river (Plate 8). These spills originated both from industrial discharges (Plate 9) and from commercial shipping traffic (Plate 10).

Good association was established in relating the presence of oily and tarry substances, elevated loss on ignition (LOI) values and petrochemical odours in the sediments to the macroinvertebrate associations defined.

Analyses indicated a wide range of values for loss-on-ignition and solvent extractables along the Canadian shoreline. Of the 35 industrial sampling sites, 32 yielded sediments that were physically suitable for the analysis of solvent extractables (i.e. fine-grained materials). Of these, 50 percent produced solvent extractable concentrations greater than 1500 mg/kg, the Ministry of the Environment's Marine Construction Guideline above which sediments are classified as contaminated. Samples at three stations located at the downstream extremity of Polysar Limited yielded concentrations of 16,500 mg/kg.

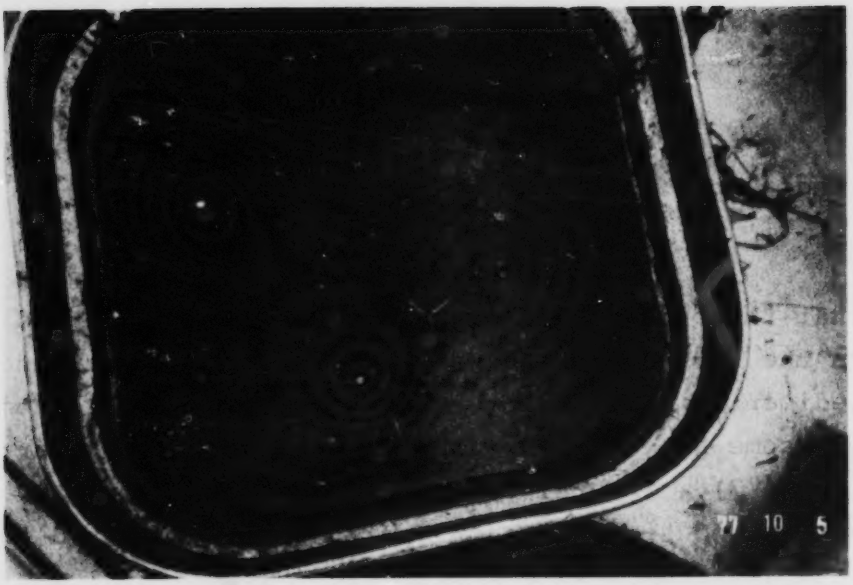

Plate 7. Oil globules originating from bottom sediments.

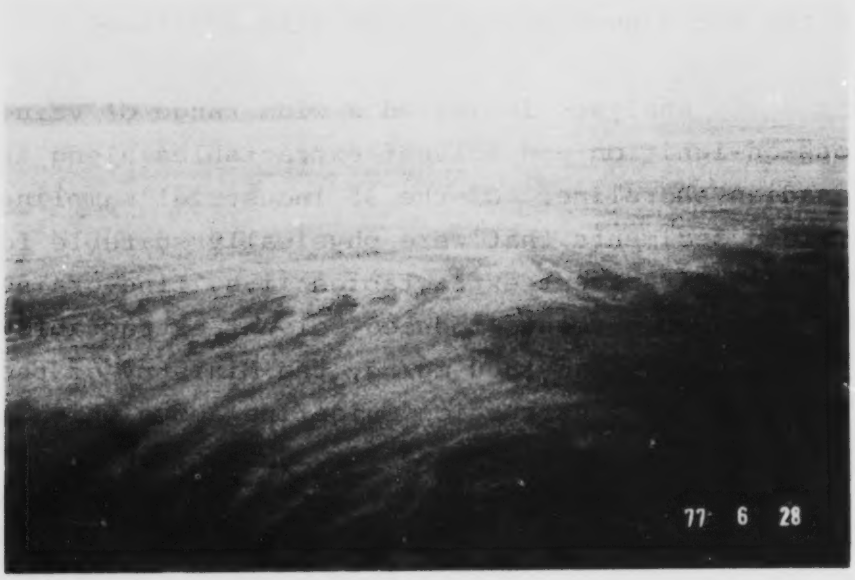

Plate 8. Oil spill from freighter on the lower St. Clair River.

Plate 9. Oil spilled on shoreline from industrial outfall.

Plate 10. Spill from docked ship during cargo handling.

At sixteen percent of the industrial sites, LOI values exceeded the Marine Construction Guideline of six percent. Two of these stations located offshore from Polysar Limited produced sediments with a LOI of 22 percent while sediments at the mouth of Baby Creek yielded a LOI of 15 percent.

At the river sampling stations, located farther offshore, concentrations of solvent extractables were generally lower. However, at Station 22 (offshore from Polysar Limited) a concentration of 28,000 mg/kg was documented. Only river stations 10, 20 and 22 had LOI values greater than six percent.

Mercury

At total of 25 sediment samples were analysed from along the Canadian shore for mercury during 1969 when a maximum concentration of 1470 mg/kg was detected offshore from Dow Chemical of Canada Limited. This sampling was the first documentation of mercury in the sediments of the St. Clair River. During the 1977 survey, a total of 84 samples were analysed from sediments collected along the Canadian shore. All samples were analysed using "aqua regia" digest - flameless AAS procedure. A much reduced maximum concentration of 58 mg/kg was again detected offshore from Dow Chemical of Canada Limited. These results support the recognized deline of mercury concentrations in the surficial sediments of the St. Clair River (Table 9). The 1977 mean concentration was 3.1 mg/kg which is still ten times the Marine Construction Guideline of 0.3 mg/kg in excess of which sediments are not considered safe for open water disposal.

Table 9. Concentrations of mercury (mg/kg) in surficial sediments of the Canadian portion of the St. Clair River.

Date	Sample size	Maximum	Minimum	Mean	Standard deviation
1969	25	1470	0.79	252	± 438
1977	84	58	0.04	3.1	± 7.1

Other Metals

During 1969, high concentrations of zinc, copper, lead and iron were documented offshore from Mueller Limited which was discharging wastes directly to the river. At the time of the 1977 survey, wastes from Mueller Limited were being directed to the Sarnia Sewage Treatment Plant and marked reductions were documented in the maximum concentrations of zinc, copper and lead. Despite the decrease in the maximum concentrations, average concentrations of zinc, copper and lead increased along the Canadian side of the river (Table 10). The maximum and average concentrations of iron decreased slightly from 1969 to 1977. The maximum and average concentrations of manganese were essentially unchanged from 1969 to 1977.

Most stations in 1977 contained concentrations of metals in excess of the Ministry of the Environment's Marine Construction Guidelines. At such concentrations sediments are considered contaminated and not safe to deposit

Table 10. Concentrations of metals (mg/kg) in sediments from the Canadian portion of the St. Clair River, 1969 and 1977.

	Average concentration		Maximum concentration	
Parameter	1969[a]	1977[b]	1969	1977
Zn	75	218	19,800	1,020
Cu	38	58	11,100	740
Pb	29	43	1,200	460
Fe	9,747	5,783	21,000	18,800
Mn	135	130	380	330
Ca	60,380	42,800	457,000	78,100

a All 1969 samples analysed by AAS following "aqua-regia" digestion.

b 1977 Fe, Mn and Ca samples were analysed using a 3.4 m Ebert Convertible D.R. Spectrometer/ICAP Excitation. Zn, Cu and Pb samples analysed by AAS.
All analyses followed "aqua-regia" digestion.

in open waters. While only fourteen percent of the stations exceeded the 50 mg/kg guideline for lead, 97 percent exceeded the 25 mg/kg guideline for chromium. Thirty-four and 60 percent of the stations exceeded the guidelines for zinc (100 mg/kg) and copper (25 mg/kg), respectively. Markedly increased concentrations of zinc (3800 mg/kg) and copper (610 mg/kg) occurred immediately downstream from Mueller Limited. Six stations exceeded the guideline for iron (10,000 mg/kg), the farthest upstream violation also occurring immediately downstream from Mueller Limited (16,700 mg/kg). The maximum concentration for iron (18,800 mg/kg) was documented downstream from Dow Chemical of Canada Limited's steam plant discharge. The maximum concentration for nickel was once again located immediately downstream from Mueller Corporation Limited, 15 metres offshore.

During 1969, a white precipitate of calcium carbonate covered the bottom offshore from Dow Chemical of Canada Limited. Although still covered with a heavy precipitate in 1977, the quantity was noticeably reduced as reflected by decreases in the average and especially the maximum concentrations of calcium in the sediments.

Concentrations of chromium and nickel were in excess of the guidelines (for open water disposal) at the control station in Lake Huron, approximately 3 kilometres from the mouth of the river and immediately east of the shipping channel. Disposal of dredged materials is occurring in the vicinity of the control station and may be an explanation for the contaminated sediments.

WATER CHEMISTRY

Surface Water

A review of the data from the six surface water samplings at the biological sampling locations indicated several areas of water quality impairment.

Upstream stations indicated an ambient total organic carbon (TOC) concentration of approximately 2 mg/l. Three stations exhibited a noticeable variance from this background concentration. Station 20 (downstream from Imperial Oil Limited) produced an average TOC concentration of 6.4 mg/l. Stations 22 (downstream from Polysar Limited) and 64 (at the mouth of Marshy Creek - Port Lambton Lagoons) yielded average TOC concentrations of 5.9 and 4.6 mg/l, respectively. The increased TOC concentrations at Imperial Oil Limited and Polysar Limited coincided with the commencement of the extensive bacterial slime growths along the Canadian side of the river.

Although no stations exhibited average total phosphorus concentrations in excess of the guideline established to avoid excessive plant growths (i.e. <30 mg/l), 19 percent of the stations were characterized by maximum concentrations in excess of this guideline. Station 56 (downstream from Canadian Industries Limited) provided the highest concentration (77 µg/l) of total phosphorus documented.

The average ambient concentration of dissolved solids was approximately 130 mg/l. The Provincial Water Quality Objective for total dissolved solids (Ontario Ministry of the Environment, 1978) states that concentrations should

not increase "by more than 1/3 of the natural concentrations to protect aquatic life". Although a number of stations exhibited average total dissolved solids concentrations noticeably in excess of average background concentrations only two stations approached the Objective. Station 24 (immediately downstream from Dow Chemical of Canada Limited) yielded an average concentration of 169 mg/l and a maximum concentration of 216 mg/l. Station 32 (immediately upstream from the mouth of Talford Creek) exhibited an average concentration of 165 mg/l and a maximum of 189 mg/l. An additional 14 percent of the stations had maximum concentrations in excess of 200 mg/l.

Variations were noticeable in the concentrations of free ammonia from station to station; however, average concentrations were all less than the Objective to protect aquatic life (0.02 mg/l un-ionized ammonia).

Other surface water parameters demonstrated little variability from station to station and met Objectives for the protection of aquatic life. Maximum, minimum and average values for selected surface water parameters are found in Table 11.

Bottom Water

Far greater variation was exhibited in chemical concentrations in bottom waters as compared to surface waters. Figure 14 demonstrates this variation for five parameters at thirty-five sampling locations. Effluents from Shell Canada Limited discharge to Talford Creek.

Table 11. Values for chemical parameters in surface waters at biological sampling locations[a].

	Hardness as $CaCo_3$	Alkalinity as $CaCo_3$	pH	Phosphorus		Nitrogen		Solids		Carbon		Chlorides	Conductivity ($\mu mho/cm^3$).
				Total	Soluble	Kjeldahl	Total	Total	Dissolved	T.O.C.	Total		
Maximum	104	97.6	8.77	0.077	0.023	2.100	2.420	238	219	27.0	46.5	35.0	320
Minimum	94	74.4	7.81	0.002	0.001	0.105	0.338	96	85	0.5	17.5	6.0	204
Average	99	80.6	8.32	0.012	0.002	0.214	0.458	143	135	3.1	20.7	11.5	226

[a] Results in mg/l except where otherwise noted.

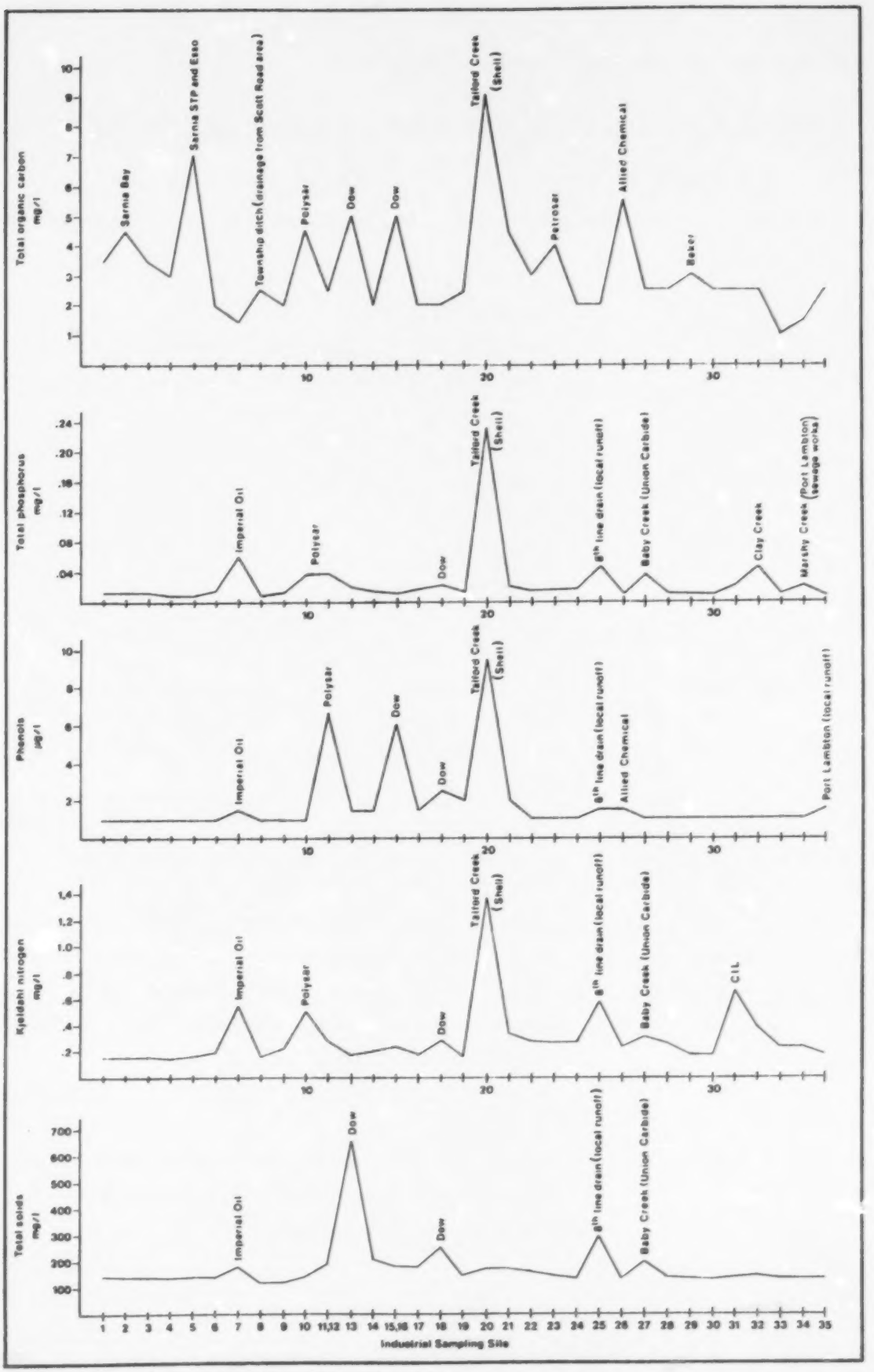

Figure 14. Concentrations for five parameters in bottom waters at industrial sampling sites.

Table 12. Bottom water sampling locations.

Station number	Station description
1	Control station in Lake Huron
2	Sarnia Bay
3	Imperial Oil Limited - No. 3 separator sewer
4	Imperial Oil Limited - No. 5 separator sewer
5	Esso Chemical Canada Limited (pressure sewer) and STP
6	Imperial Oil Limited - No. 9 separator sewer
7	Imperial Oil Limited - extended outfall (bioxidation effluent, No. 11 separator sewer, No. 12 separator sewer)
8	Township ditch (drainage from Scott Road area)
9	Polysar Limited - 54 inch sewer
10	Polysar Limited - stereo API discharge
11 & 12	Polysar Limited - 66 inch and 72 inch sewers
13	Dow Chemical of Canada Limited - 42 and 48 inch sewers, acid tile
14	Dow Chemical of Canada Limited - 2nd Street sewer
15 & 16	Dow Chemical of Canada Limited - 3rd Street sewer and DOEO
17	Dow Chemical of Canada Limited - 4th Street sewer
18	Dow Chemical of Canada Limited - steam plant
19	Sunoco Incorporated - total plant discharge
20	Mouth of Talford Creek (including outfalls from Shell Canada Limited)
21	Ethyl Corporation of Canada Limited - total plant discharge
22	Dupont Canada Incorporated - total plant discharge
23	Petrosar Limited - total plant discharge
24	Corunna sewage treatment plant

Table 12. continued

Station number	Station description
25	Union Carbide Canada Limited (8th line drain)
26	Allied Chemical Canada Ltd.
27	Mouth of Baby Creek (including runoff from Petrosar Limited and Union Carbide Canada Limited)
28	Ontario Hydro - Lambton Generating Station
29	Beker Industries of Canada Limited
30	Mouth of Bowens Creek
31	Canadian Industries Limited
32	Mouth of Clay Creek
33	Chinook Chemicals Limited (Murphy Drain)
34	Marshy Creek (Port Lambton lagoons)
35	Offshore from Port Lambton

The effects from these discharges were measured right at the mouth of Talford Creek and may be elevated due to less available dilution than effluents discharging directly to the St. Clair River. Elevated nutrient concentrations at the mouth of Talford Creek may be partially a result of general basin runoff.

The water quality guideline for phosphorus to prevent excessive plant growth in rivers is 30 µg/l. This guideline was exceeded at 20 percent (7 stations) of the bottom water sampling locations. The two highest concentrations coincided with two areas of heaviest aquatic plant growths. These two areas were downstream from Imperial Oil Limited and the mouth of Talford Creek (Shell Canada Limited) where total phosphorus concentrations of 67 and 234 µg/l were detected, respectively.

Concentrations of phenols in bottom waters exceeded the Provincial Water Quality Objective of 1 µg/l (for the protection of fish from tainting) at 60 percent of the sampling locations. A maximum concentration of 9.5 µg/l was documented at the mouth of Talford Creek (Shell Canada Limited).

The principal contributor of total dissolved solids was Dow Chemical of Canada Limited whose discharges resulted in a concentration of 571 mg/l at industrial sampling site number 13. This is reflected in Figure 14 where total solids at Station 13 reached 644 mg/l, the maximum concentration documented in the river. There is no Objective for total solids; however, the dissolved solids concentration at Station 13 was in excess of the Objective to protect aquatic life (1/3 above ambient or approximately 175 mg/l). Two additional Dow outfalls also resulted in dissolved solids

concentrations exceeding the Objective at stations 14 and 18. Two other sampling locations, (stations 25 and 27) exceeded the Objective. These stations reflected inputs from the 8th line drain and Baby Creek, respectively. Baby Creek receives site runoff from Petrosar Limited and Union Carbide Canada Limited.

Although there is no Provincial Water Quality Objective for TOC, there were wide fluctuations in the concentrations of this parameter in bottom waters along the Canadian shore.

In addition to the parameters depicted in Figure 14, free ammonia concentrations varied noticeably in bottom waters in the immediate vicinity of discharges from Talford Creek (Shell Canada Limited), Allied Chemical Canada Ltd. and Canadian Industries Limited. At the mouth of Talford Creek, the ammonia concentration exceeded the Objective for the protection of aquatic life (0.02 mg/l un-ionized ammonia). This was the only location documented as having exceeded this Objective and is reflected in Figure 14 by the high peak for total Kjeldahl nitrogen (which includes ammonia).

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APPENDIX 1

Appendix 1. Macroinvertebrates collected at 60 stations in the St. Clair River (Numbers per m^2) July, August, 1977.

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
STONEFLIES																
Perlesta placida																
MAYFLIES																
Baetis																
Caenis																
Ephemerella																
Hexagenia limbata							7	7			7					
Pseudocleon					7											
Stenonema					20											
unidentified																
CADDISFLIES																
Agraylia												7				
Athripsodes				7												
Brachycentrus												20		20		
Cheumatopsyche				13									7			
Hydropsyche				46	33											
Oecetis																
Polycentropus																
Pycnopsyche																
Pupae (unidentified)				7	26		13					7				

a = stations located in U. S. waters

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
STONEFLIES																
Perlesta placida																
MAYFLIES																
Baetis						7										
Caenis																
Ephemerella																
Hexagenia limbata		13														
Pseudocleon																
Stenonema																
unidentified																
CADDISFLIES																
Agraylia																
Athripsodes																
Brachycentrus						26										
Cheumatopsyche				33		13						20		7		
Hydropsyche																
Oecetis																
Polycentropus																
Pycnopsyche																
Pupae (unidentified)		20														

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
STONEFLIES																
Perlesta placida								7								
MAYFLIES																
Baetis		7														
Caenis		7														
Ephemerella																
Hexagenia limbata						5										
Pseudocleon																
Stenonema																
unidentified																
CADDISFLIES																
Agraylia																
Athripsodes																
Brachycentrus												40				
Cheumatopsyche						15			85			20				
Hydropsyche												7				
Oecetis																
Polycentropus									7							
Pycnopsyche																
Pupae (unidentified)						5		7	13			20				

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
STONEFLIES												
Perlesta placida							7					
MAYFLIES												
Baetis												
Caenis			13	7				7				
Ephemerella												
Hexagenia limbata							46		7		33	26
Pseudocleon												
Stenonema												
unidentified												
CADDISFLIES												
Agraylia												
Athripsodes					7							7
Brachycentrus					7		13		7	7		
Cheumatopsyche						7	7	7				
Hydropsyche												
Oecetis												
Polycentropus												
Pycnopsyche			13									
Pupae (unidentified)			13	7								

Appendix 1. - continued

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
LEPIDOPTERA																
Elophila																
DRAGONFLIES																
Gomphus																
TRUE BUGS																
Corixidae																
Adult (unidentified)																
BEETLES																
Elmidae																
MITES						20	7									
AMPHIPODA																
Gammarus	7					7	105	1 13	20		13					20
Hyalella azteca			7													
Pontoporeia affinis						13		7			59					
Unidentified																

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
LEPIDOPTERA																
Elophila		13	10								7					
DRAGONFLIES																
Gomphus																
TRUE BUGS																
Corixidae											7					
Adult (unidentified)													26		7	
BEETLES																
Elmidae																
MITES													20			7
AMPHIPODA																
Gammarus	7	118		46	7	7								79		
Hyalella azteca				13											7	
Pontoporeia affinis														20		
Unidentified																

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
LEPIDOPTERA																
Elophila		79	7			5	13								5	
DRAGONFLIES																
Gomphus																
TRUE BUGS																
Corixidae															5	
Adult (unidentified)																
BEETLES																
Elmidae																
MITES		7			7				26	33					49	
AMPHIPODA																
Gammarus		66	63		7	69	20	13	79	7	20	85		164	172	7
Hyalella azteca			7													
Pontoporeia affinis											7					7
Unidentified																

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
LEPIDOPTERA												
Elophila												26
DRAGONFLIES												
Gomphus										13		
TRUE BUGS												
Corixidae										7		
Adult (unidentified)												
BEETLES												
Elmidae												
MITES	20	13	7	20	26		20	26		13	7	
AMPHIPODA												
Gammarus	85	7	637	13	7	39	171	1418	296	46	460	630
Hyalella azteca			13									
Pontoporeia affinis			7	20								
Unidentified												

Appendix 1. - continued

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
ISOPODA																
Asellus							1248	20			7	7				
CRAYFISHES																
Orconectes propinquus					7											7
SNAILS																
Amnicola							125				355					7
Bithinia tentactulata																
Campeloma								7								
Goniobasis	13		7	13	26							20	20			39
Gyraulus							66									
Lymnaea					7		7							20		
Physa							52									
Pleurocera																
Somatogyrus								7								
Valvata sincera							20	13								
Valvata tricarinata							33									
CLAMS																
Pisidium	7		7			26	131	59			7					
Sphearium											20					

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
ISOPODA																
Asellus		7														
CRAYFISHES																
Orconectes propinquus									7					14		7
SNAILS																
Amnicola		13													13	
Bithinia tentactulata		7														
Campeloma																
Goniobasis				118	13		105	20			13	13		13		26
Gyraulus											20					
Lymnaea	7		20	59							20				20	322
Physa	40	99	156			20			13	328	959	7	59	13	171	696
Pleurocera																
Somatogyrus																
Valvata sincera											552					
Valvata tricarinata																
CLAMS																
Pisidium	7										20		7		7	
Sphearium																

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
ISOPODA																
Asellus		7														
CRAYFISHES																
Orconectes propinquus	7	7														
SNAILS																
Amnicola		26	7			10	33					7		7	5	
Bithinia tentactulata																
Campeloma																
Goniobasis		105	7	20		10	53	53	7	59	7	309		7	49	
Gyraulus		171	26		20		79			53					20	
Lymnaea	112	20	39		7	5	53			13		86	7	26	20	
Physa	2410	230	2515	7	2574	5	328		40	46		79	7	53	40	
Pleurocera																
Somatogyrus																
Valvata sincera	66	13			53	10	13							164	49	
Valvata tricarinata					7		151			7				99	104	
CLAMS																
Pisidium	33	7	7		26	133				13		13		387	84	
Sphearium																

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
ISOPODA												
Asellus								66				
CRAYFISHES												
Orconectes propinquus						7						
SNAILS												
Amnicola	20		20	33	20			13	7	7	20	7
Bithinia tentactulata												
Campeloma												
Goniobasis	118	13			20	40	20	46	66		79	
Gyraulus		7	7		7		39	99	13	13	33	
Lymnaea	7	7	20				13	7			7	
Physa	66				53	13	46	230	13	125	20	60
Pleurocera												
Somatogyrus												
Valvata sincera	33	13	512		263			79		33		26
Valvata tricarinata	13	7	663		26			59	13	33	39	
CLAMS												
Pisidium	13	59	26	33	99		46	20	20	20	7	
Sphearium												

Appendix 1. - continued

ORGANSIMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
LIMPETS																
Ferrissia																
TRUE FLIES (unidentified pupae)	7					20	26	20	13	13		7				
Culicidae																
Ceratopogonidae			7													7
Rhagionidae																
Chironomidae																
Chironominae	7	7	7			7										
Chironomus						253	137	959	647		90					
Cryptochironomus	7	7	85		7	93	34	129	43		41					
Dicrotendipes																
Glyptotendipes																
Microtendipes																
Paracladopelma																
Parachironomus						42	50				21					
Paralauterborniella																
Paratendipes							13						7			
Phaenopsectra						76										
Polypedilum						7	120		79		344		7	10		
Stenochironomus																

Appendix 1. - continued

ORGANSIMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
LIMPETS																
Ferrissia																
TRUE FLIES (unidentified pupae)						7			7			33				
Culicidae																
Ceratopogonidae																
Rhagionidae																
Chironomidae																
Chironominae													33			
Chironomus	7	627	25		7				40	13	7		61	16	19	7
Cryptochironomus		157		20	13				73	46			113	69	112	
Dicrotendipes																
Glyptotendipes																
Microtendipes		7														
Paracladopelma													56	16	21	
Parachironomus												16		7		
Paralauterborniella																
Paratendipes																
Phaenopsectra																
Polypedilum		20		7			7									
Stenochironomus																

Appendix 1. - continued

ORGANSIMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
LIMPETS																
Ferrissia																
TRUE FLIES (unidentified pupae)	7		7			20										
Culicidae																
Ceratopogonidae																
Rhagionidae																
Chironomidae																
Chironominae																
Chironomus	48	264	25		28	229	7		39				20		12	13
Cryptochironomus	21	7	125	7	40	267	33		125	30			33	353	202	236
Dicrotendipes																
Glyptotendipes																
Microtendipes									7							
Paracladopelma													7			
Parachironomus																
Paralauterborniella																
Paratendipes																
Phaenopsectra																
Polypedilum			18										7			72
Stenochironomus																

Appendix 1. - continued

ORGANSIMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
LIMPETS												
Ferrissia												
TRUE FLIES (unidentified pupae)				13						7		
Culicidae												
Ceratopogonidae										39		
Rhagionidae												
Chironomidae												
Chironominae												
Chironomus	7						373					92
Cryptochironomus	72	201	82	95				25	33	86	199	306
Dicrotendipes												
Glyptotendipes	7		401					25	13		44	
Microtendipes												
Paracladopelma												
Parachironomus			62					25			22	
Paralauterborniella												
Paratendipes												
Phaenopsectra												
Polypedilum	7	442	200	95			642	12			22	57
Stenochironomus												

Appendix 1. - continued

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
Chironomidae cont'd																
Strictochironomus						23										
Tribelos							44		132							
Tribe Tanytarsini																
Micropsectra																
Orthocladiinae					185											
Cardiocladius																
Crictopus																
Heterotrissocladius											42					
Psectrocladius					51									10	7	
Corynoneura		7			13					328		26		10		
Tanypodinae																
Procladius							277	95	106		132					
Tribe Pentaneurini	7			39			29	24								
Diamesinae																
Potthastia longimanus																
Monodiamesa																
Pupae (unidentified)																
WORMS																
Tubificidae																
Aulodrilus americanus						17	403	780			37					
A. pluriseta																
Branchiura sowerbyi																
Ilyodrilus templetoni						184			54							

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
Chironomidae cont'd																
Strictochironomus		20														
Tribelos		29							34		7		7		148	
Tribe Tanytarsini																
Micropsectra																
Orthocladiinae (unidentified)																
Cardiocladius																
Crictopus	190	7	123			26			41	26	13				7	
Heterotrissocladius																
Psectrocladius	7															
Corynoneura	13											78				
Tanypodinae												255				
Procladius		13														
Tribe Pentaneurini		7							81	13	79		11		13	
Diamesinae									61	7	7		16		9	46
Potthastia longimanus																
Monodiamesa		7														
Pupae (unidentified)										7				18		
WORMS																
Tubificidae																
Aulodrilus americanus		51														
A. pluriseta		85														
Branchiura sowerbyi																
Ilyodrilus templetoni	59	43												13		

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
Chironomidae cont'd																
Strictochironomus																
Tribelos	21	38	11	7		38				10				148	33	20
Tribe Tanytarsini																
Micropsectra																
Orthocladiinae																
Cardiocladius																
Crictopus	12			7					26							
Heterotrissocladius																
Psectrocladius																
Corynoneura																
Tanypodinae																
Procladius	123		24		299	76										
Tribe Pentaneurini	45		149	7	28		20		13	13				35	114	
Diamesinae														35	74	
Potthastia longimanus			9													
Monodiamesa																
Pupae (unidentified)													7			
WORMS																
Tubificidae																
Aulodrilus americanus		38														
A. pluriseta																
Branchiura sowerbyi													49			
Ilyodrilus templetoni					115									17		

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
Chironomidae cont'd												
Strictochironomus												
Tribelos	7		7		1415		406		7	184		
Tribe Tanytarsini												
Micropsectra												
Orthocladiinae												
Cardiocladius												
Crictopus												
Heterotrissocladius												
Psectrocladius			62									
Corynoneura												
Tanypodinae												
Procladius			89		109		267	12			22	77
Tribe Pentaneurini	20		200			13	13				44	
Diamesinae												
Potthastia longimanus										7		7
Monodiamesa				7								
Pupae (unidentified)												
WORMS												
Tubificidae												
Aulodrilus americanus				110			58					
A. pluriseta								7		40	25	
Branchiura sowerbyi										20		
Ilyodrilus templetoni										17		

Appendix 1. - continued

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
Tubidicidae cont'd																
Limnodrilus angustipenis																
L. cervix						57			314							
L. claparedeianus									88							
L. hoffmeisteri				7		385	1478	832	928						7	
L. maumeensis							1060	1368			367					
L. profundicola																
L. udekemianus								163								
Peloscolex ferox						107	438	601	181		59					
P. freyi						51					170					
P. multisetosus								255								
Potamothrix moldaviensis						124	67		27							
Tubifex ignotus																
Tubifex tubifex								616	60							
Unidentified (hair chaeta absent)			13			1333	6151	3542	1011		700	7				
Unidentified (hair chaeta present)			7					698	60							
Lumbriculidae																
Stylodilus heringianus					13	17			60		35					
Naididae																
Nais bretscheri																
N. communis																

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
Tubidicidae cont'd																
Limnodrilus angustipenis																
L. cervix		85									2189		679		55	21
L. claparedeianus	27									56	310					
L. hoffmeisteri	59	470	2230		1064	7			123	1229	9932		3129		400	164
L. maumeensis																
L. profundicola										55						
L. udekemianus		43	279						16		653					21
Peloscolex ferox		189					7			56	323			46		20
P. freyi		45														
P. multisetosus	27								72	56	323					
Potamothrix moldaviensis		150														
Tubifex ignotus																
Tubifex tubifex			64						72	165	686		1216		193	
Unidentified (hair chaeta absent)	160	664	857		959	13			887	2582	10890		6424	26	4163	260
Unidentified (hair chaeta present)			107								482		241		48	21
Lumbriculidae																
Stylodilus heringianus	59			26												
Naididae																
Nais bretscheri				13												
N. communis	59	43														

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
Tubidicidae cont'd																
Limnodrilus angustipenis																
L. cervix	243	75	7		115											
L. claparedeianus	71															
L. hoffmeisteri	821	833	37	19	2215								65	17	75	
L. maumeensis		150														
L. profundicola																
L. udekemianus					115								16			
Peloscolex ferox	430		51	7	361	325	72		25					7	1641	20
P. freyi																
P. multisetosus	344		25		806		65								13	
Potamothrix moldaviensis									50				16			20
Tubifex ignotus			49													
Tubifex tubifex	71		37		14											
Unidentified (hair chaeta absent)	7352	651	573	206	2489	16	835		76				195	85	166	
Unidentified (hair chaeta present)	71				603									34		
Lumbriculidae																
Stylodilus heringianus			61	19	186		20	13		13	13	85	13	7	27	20
Naididae																
Nais bretscheri																
N. communis			7							26				204	58	

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
Tubidicidae cont'd												
Limnodrilus angustipenis												
L. cervix			26				338					
L. claparedeianus												
L. hoffmeisteri	7	332	7		518		45			316		98
L. maumeensis							52					117
L. profundicola												
L. udekemianus										37		20
Peloscolex ferox	92	111	104	159	207		19	20		236	70	53
P. freyi		55										
P. multisetosus												
Potamothrix moldaviensis		166		15			207		7	100		104
Tubifex ignotus												
Tubifex tubifex												
Unidentified (hair chaeta absent)	85	1496	352	53	483		317	26		267	63	345
Unidentified (hair chaeta present)										70		7
Lumbriculidae												
Stylodilus heringianus	53		33			79		66	66		33	
Naididae												
Nais bretscheri												
N. communis			234									

Appendix 1. - continued

ORGANISMS	1[a]	2	3[a]	5[a]	6	7[a]	8	10	11[a]	12	13	14	15	16[a]	18	19[a]
Naididae cont'd																
N. pseudobtusa																
Ophidonais supentina							107									
Stylaria lacustris																
Uncinais uncinata											7					
Unidentified																
LEECHES							72				7					
FLATWORMS	7			7	20		26							30		7
ROUNDWORMS																
NO. TAXA =	7	2	7	7	12	17	28	19	14	1	20	6	4	6	2	6
NO. ORGANISMS =	62	21	140	139	415	2862	13292	10215	3823	341	2520	101	41	100	14	87

Appendix 1. - continued

ORGANISMS	20	21[a]	22	23[a]	24	26	27[a]	28	29	30	32	33b	34	35[a]	36	37
Naididae cont'd																
N. pseudobtusa	27	43														
Ophidonais supentina	7	43														
Stylaria lacustris																
Uncinais uncinata																7
Unidentified																
LEECHES	7										309					
FLATWORMS	7					7					13					
ROUNDWORMS														7		
NO. TAXA	19	30	8	10	5	8	3	1	11	12	22	6	13	13	16	11
NO. ORGANISMS	783	3138	3871	348	2063	133	119	20	1527	4639	27821	422	12098	364	5413	1618

Appendix 1. - continued

ORGANISMS	38	39[a]	40	41	42	43[a]	44	46	47[a]	48	50	51[a]	52	53	54	55[a]
Naididae cont'd																
N. pseudobtusa															14	
Ophidonais supentina													17			
Stylaria lacustris	7		7													
Uncinais uncinata																
Unidentified																
LEECHES			7			10	7							13	10	
FLATWORMS	13	33				15	13		13			26				13
ROUNDWORMS																
NO. TAXA	19	22	27	9	20	17	17	5	14	13	4	11	12	19	24	10
NO. ORGANISMS	12328	2841	3914	306	10109	1268	1815	93	631	323	47	777	442	1879	3041	428

Appendix 1. - continued

ORGANISMS	56	58	59	60[a]	61	62	63[a]	64	65	66	68	69[a]
Naididae cont'd												
N. pseudobtusa			26					7				
Ophidonais supentina			78									
Stylaria lacustris												
Uncinais uncinata												
Unidentified												
LEECHES	13		7		59				53	7	7	
FLATWORMS	7		20		13	7	52	7				33
ROUNDWORMS												
NO. TAXA	20	14	29	12	17	8	23	23	15	24	20	18
NO. ORGANISMS	752	2929	3941	680	3339	205	3217	2309	621	1770	1256	2098